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THE

JOURNAL OF GEOLOGY

A Semi-Quarterly Magazine of Geology and Related Sciences

VOLUME III

1895

CHICAGO

The University of Chicago Press

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THE

JOURNAL OF GEOLOGY

JANUARY-FEBRUARY, 1895.

THE BASIC MASSIVE ROCKS OF THE LAKE SUPERIOR REGION.

IV. THE PERIPHERAL PHASES OF THE GREAT GABBRO MASS IN NORTHEASTERN MINNESOTA.[1]

C. The Granulitic Gabbros.

THE granulitic gabbros include a large number of different phases characterized by the same general type of structure, but differing from one another in mineralogical composition. Olivinitic varieties occur in small quantity. In these the constituents are the same as those composing the great mass of the normal gabbro, viz., magnetite, olivine, diallage and plagioclase. The rarity of olivine in the granulitic rocks is in marked contrast with its abundance in the gabbroitic variety. In the latter, if one of the components is absent it is usually the diallage. In the granulitic phase, olivine is more frequently absent than present. By its loss diallagic varieties result. But pure diallagic phases of the granulitic rocks are also uncommon, for in the production of the granulitic structure there is a tendency to the formation of biotite and hornblende. Thus biotitic and hornblendic varieties are much more common among the granulitic gabbros than among those with the true gabbro structure. Another quite widely spread constituent in the granulitic rocks is hypersthene. In these, as in the non-feldspathic gabbros, this mineral appears to take the place of olivine.

[1] Continued from this Journal, Vol. II., p. 825.

The Olivinitic Varieties.—The few olivine-bearing granulitic gabbros studied are from places but a very short distance south of the north limit of the gabbro area, and not far north of localities where the normal gabbro occurs in its usual form. They appear to be intermediate in character between the gabbro and the typical granulitic rocks. Their structure is not purely granulitic, for the pyroxene in them is in polysomatic masses rather than in individual rounded grains, although in the same section there may be found in addition to the polysomatic masses a few isolated grains of augite and some compact plates of the same mineral.

The olivine is in fairly large, colorless or light yellow, irregular grains, whose cleavage cracks are marked by grains of magnetite and masses of limonite. Magnetite also occurs as small dust-like particles in their peripheral portions. Green earthy decomposition products surround many of the fresh olivines and extend into their interiors along irregular cracks, and out into the minerals that are contiguous to them. A feature of great significance in connection with the olivine is the fact that many of its grains are surrounded by narrow rims of augite, just as are the olivine grains in the normal gabbro.[1] Since this method of association of the two minerals is so characteristic for the gabbro, which is undoubtedly an igneous rock, there can be no question that the olivine granulitic rocks, though bedded, are closely related to the gabbro, and like this rock are also igneous, and are not metamorphosed sediments. Unfortunately, most of the granulitic rocks contain no olivine, so that the application of this means of identifying them as portions of the great gabbro is very limited.

The diallage appears to be next in age to the olivine. It is in small rounded grains, either isolated or in aggregates so united as to form large masses. The individual grains of the aggregates are often separated from each other by narrow seams of limonite, or by small grains of magnetite, and in their midst is not infrequently a grain of olivine. The mineral is nearly colorless. It possesses the normal prismatic cleavage of augite, and in addi-

[1] See this Journal, Vol. I., p. 702, Fig. 1, and p. 706, Fig. 3.

tion another that reveals itself as a series of very fine lines parallel to the coarser lines of the prismatic cleavage. Its inclusions are little particles of magnetite, small plates of biotite, tiny masses of green and brown earthy matter and a few glass particles.

The existence in these rocks of an aggregation of many small rounded grains of augite in the place of the large plate of this mineral in the true gabbro is strongly suggestive of the polysomatic augites discovered by Lawson[1] in the diabase of certain dikes in the Rainy Lake region, Canada. In the Minnesota rocks the polysomatization of the augite seems to be an intermediate step in the granulitization of the gabbro, not, however, in the sense that all the granulitic rocks have passed through this stage at some time in their history, but in the sense that the polysomatization of the augite is the result of a force similar in character to that which produced granulitization in the granulitic rocks but less efficient in its action.

The plagioclase of these rocks is in allotriomorphic grains of varied sizes and of very irregular shapes in those portions of sections that are poor in augite, and in small and more or less rounded grains where rounded augites and olivines are found. For the most part the feldspar is quite fresh, but here and there little accumulations of kaolin occur in it, and small bunches of green chloritic substance fill the interstices between the neighboring grains. Under low powers all the plagioclase appears to be filled with dust, but this dust under high power is resolved into long needles and small plates of opaque or dark brown substances, and tiny irregular glass inclusions. A few long, narrow, quadrangular cavities and some elliptical ones seem to be filled with liquid, but they are in all cases so minute that it cannot be certain that this is the case. All the inclusions of this character are usually heaped toward the centers of the feldspar grains, with a zone of clear plagioclase around them. In addition to these inclusions there are also imbedded in the feldspar a few rounded grains of augite, and of magnetite, and along the edges of the last named mineral flakes of reddish brown biotite.

[1] Proc. Can. Inst. 1887, Toronto, 1888.

As to the nature of the plagioclase it is difficult to draw accurate conclusions. Measurements of the extinction angles of contiguous twinned lamellæ indicate a labradorite. The most noticeable difference between the plagioclase of these rocks and that of the true gabbro is with respect to their twinning bars. In the latter rock the lamellæ are broad and but few in number, and but one set occurs. In the granulitic rocks the striations are narrow and very numerous. Moreover there are two sets of them inclined to each other at angles of about 90°, and the lamellæ in each set frequently wedge out toward the interiors of the grains in which they occur. Again, small areas near the centers of grains will often have two sets of lamellæ crossing each other, while in other portions of the same grains but a single parallel series is found. Such phenomena as these are usually interpreted as pointing to a secondary origin for much of the twinning in plagioclase. In the present instance a secondary twinning accompanying the granulitization of the rock would indicate that both phenomena owe their existence to common causes. Since the rocks are not sheared, the only causes that can be assigned for them are motion within the rock mass and strains produced by rapid and irregular cooling.

The magnetite, as has already been said, is to be found as small grains included in all the other primary components, and also as irregular masses between them. Whenever it comes in contact with plagioclase, there is formed around it a reaction rim of biotite.

There seems to be no definite order of succession in the formation of the various components. Sometimes the order is magnetite, olivine, pyroxene and plagioclase; at other times the plagioclase is older than the pyroxene while younger than the olivine, and again in a few instances the feldspar appears to be even older than the olivine. With respect to the age of their feldspar the granulitic rocks occupy an intermediate position between the gabbros and the diabases, in the former of which rocks the plagioclase is younger than the pyroxene, while in the latter it is the older component.

Hypersthenic Varieties.—Closely related to the olivinitic-granulitic gabbros are the hypersthene-bearing varieties. In some cases these contain a small quantity of olivine, but in most cases hypersthene has entirely replaced this mineral. A few grains of the usual colorless olivine, for instance, may be detected on one edge of the section of rock No. M. 1347, whereas elsewhere in the slide it is lacking. The main portion of the rock consists of more or less rounded grains of hypersthene and diallage, and irregular masses of magnetite, imbedded in a plexus of irregular but nearly equidimensional grains of plagioclase. Magnetite particles are included within all the rock's constituents, and, since these are very fresh, the magnetite is probably a separation from the magna. The mineral also occurs on the edges of the few olivine grains present, but here it is in long stringers that are evidently secondary.

In the great majority of the hypersthene varieties of the granulitic gabbros no trace of olivine may be detected either in the fresh or in the altered state. Their components are usually hypersthene, diallage, feldspar and magnetite. All are fresh, except in very rare cases when the feldspar shows traces of decomposition. The proportions of the pyroxenes vary widely in different specimens, even to the complete exclusion of one or the other of the two varieties. The purely hypersthenic phases are treated with the other hypersthene bearing rocks in this place, while the purely diallagic kinds are reserved for later discussion.

The hypersthene, the characteristic component of these rocks, is remarkably fresh and transparent. It is pleochroic in the usual light green and pinkish tints, and is often so compact that but few cleavage cracks are to be seen in its grains. An analysis by Dr. E. A. Schneider of a very pure powder of the mineral separated from rock No. 7036, one of the best examples of the type without diallage, gave:

SiO_2	Al_2O_3	Fe_2O_3	FeO	MnO_2	CaO	MgO	H_2O (105°)	Total[1]
48.44	7.91	.33	20.88	.92	1.44	19.35	.08	97.35

[1] TiO_2 was not determined gravimetrically. A colorimetric test showed about .40 per cent. of this oxide present.

The form of the orthorhombic pyroxene determines in large measure the structure of the rock containing it. In the most purely granulitic varieties this mineral is in the small rounded or subangular grains, which, with the similarly shaped diallage grains and those of plagioclase, together with an occasional particle of magnetite, make up the entire rock. The magnetite is included within both of the pyroxenes and the feldspar, and the pyroxenes are often also enclosed within the plagioclase. The sequence is

FIG. 1.— Granulitic gabbro, with large grains of green hornblende and small rounded ones of augite in a groundmass of plagioclase that appears in ordinary light to be a homogenous mass. The large plates of mineral to the right are hornblende. No. M 1335, x 87.

thus magnetite, pyroxene, and plagioclase, with the hypersthene probably older than the diallage. Figure 1 illustrates the structure of a rock of this kind.

A very peculiar type of structure is that resulting from the occurrence of the hypersthene in cellular grains and plates that are larger than the grains of the other constituents, and less rounded than the hypersthene of the more purely granulitic rocks. These large plates and grains are optically continuous over considerable areas, but are physically not continuous, since they are filled with small and large pores containing plagioclase of the same nature as that occurring between the hypersthene. The plates are very ragged along their edges and have many prolongations with rounded ends. The skeleton-like masses of

the pyroxene in these rocks are thus very similar in their development to the cellular cordierite, andalusite and orthoclase grains described by Salomon[1] in contact rocks. The cellular structure is thought by this writer to be so characteristic of minerals formed by contact action that he has called it the contact structure. In contact rocks it is probably due to the selection of material needed in building up the contact minerals, which would grow around the substances not needed in their construction and thus include them. In the present case the cellular structure of the hypersthene must be an original one, and the direct consequence of the conditions under which the minerals separated from the rock magma. The plagioclase, though included within the hypersthene, is probably the younger of the two minerals, just as the ice, in a frozen sponge saturated with water, is younger than the mass of the sponge which encloses it.

A third form of structure is produced by the aggregation of the hypersthene plates into groups or masses that are imbedded in the granulitic matrix from which hypersthene is wanting. The masses or groups are composed of large irregular grains of the orthorhombic pyroxene, sometimes cellular, sometimes compact, with which are intermingled many grains of diallage and an occasional one of plagioclase. Figure 2 shows a portion of one of these aggregations in the upper part of the picture. In its lower portion is the granulitic mosaic of plagioclase and diallage.

The diallage in all these rocks is in the rounded granulitic forms, except in the rare instances when it is associated with the hypersthene in the aggregates, where it is in large irregular grains. In certain of the non-hypersthenic varieties it is sometimes in cellular plates, but in those containing the orthorhombic pyroxene the diallage, when it occurs, is nearly always granulitic. In the figure last referred to the small, highly refractive, rounded grains are of this mineral. In nearly all cases the diallage is light green in color, is fresh and is without pleochroism. Its inclusions are magnetite grains, small flakes of brown mica and tiny particles of limonite.

[1] Zeits, d. d. geol. Ges., XLII., 1890, pp. 487, 511, *et seq.*

The feldspar of these rocks, like their other constituents, is on the whole very fresh. It is nearly always transparent and colorless, but here and there in some sections it contains opaque or cloudy masses of kaolin and grains of quartz. Its grains are approximately equidimensional. They do not interlock with

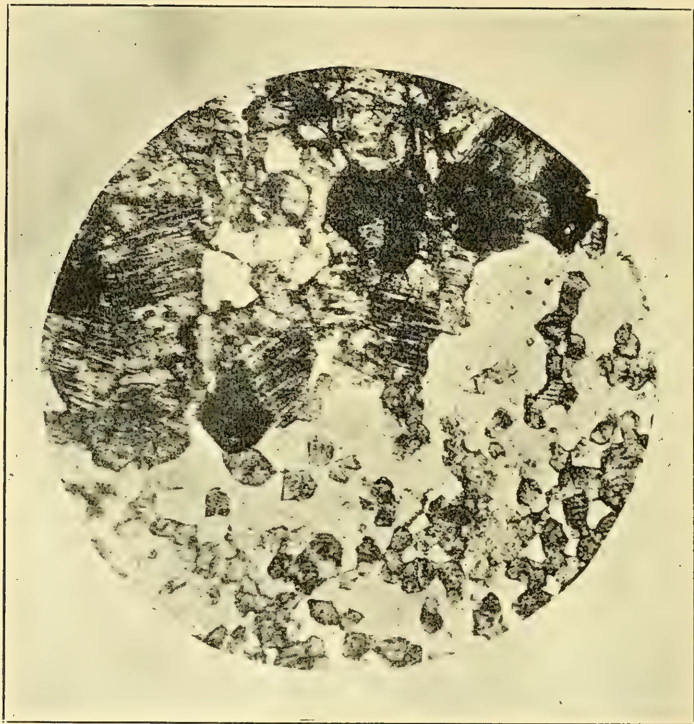


FIG. 2.—Granulitic hypersthene-gabbro with aggregates of pyroxenes. A portion of one of these aggregates is shown in the upper portion of the figure. In the lower part is seen the granulitic mosaic of diallage and feldspar No. 8879.

the irregular sutures of granitic feldspar, but they form with each other straight-edged contacts, like the grains of a micrgranitic mosaic. In many rocks these grains are of about the same size as the grains of diallage, but in others they are so small that their aggregate between crossed nicols looks very much like a micro-granitic groundmass in which the larger pyroxene grains are

imbedded. The inclusions discoverable in them are magnetite, small masses of green and brown earthy matter, much of which seems to be in pseudomorphs after magnetite, tiny opaque dust inclusions, small elliptical glass-filled cavities and a few apatite crystals. No liquid inclosures were detected in any of the fresh grains, though a few may be present in those that are slightly decomposed. The twinning of the feldspar is less complicated than was to be expected after studying the olivine-bearing granulitic rocks. Many of the grains are untwinned; more are simple Carlsbad twins; while a few show the more usual parallel bars of the polysynthetic twinning. Most of this feldspar is undoubtedly plagioclase of the same character as is found in the normal gabbro. Its optical properties so far as can be determined are like those of the gabbro feldspar, and the density of a powder separated from rock No. 8879 is 2.715. Some of the untwinned feldspar may be orthoclase, as analyses of some of the hypersthenic granulitic rocks show a large percentage of potassa.

The remaining primary component of these rocks is magnetite. It is found as tiny inclusions in the other constituents and as large grains between them, and sometimes within the pyroxene. The outlines of the grains often show traces of crystalline forms, but almost as frequently they exhibit none.

In addition to the minerals mentioned there is also often present a comparatively large quantity of biotite, but in the hypersthene varieties it seems to be less abundant than it is in those containing none of this pyroxene. When present it is in brownish green flakes so intimately associated with the hypersthene and diallage that it must needs be regarded in some cases as an alteration product of them. Not only are the little flakes abundant on the peripheries of the pyroxene grains, but they are also disseminated all through their substance as very small ill-defined specks whose strong pleochroism and brown color proclaim them to be biotite. In other rocks, in which the pyroxenes are fresh, the biotite is completely wanting, but in No. 7036, one of the freshest of all the granulitic rocks examined, the mica is very plentiful, particularly in the feldspar, as brown wisps and plates.

In this particular case, and in others like it, the biotite seems to be original, at any rate there is no evidence that it is secondary.

Chlorite is another of the unessential components of the granulitic rocks. It is however always in such small quantity that its effect upon the general aspect of these rocks is not marked.

The analyses of two specimens of the hypersthenic rocks follow:

	I.	II.
SiO_2	46.96	49.56
TiO_2	.62	.48
Al_2O_3	14.13	17.81
Cr_2O_3	tr.	
Fe_2O_3	.76	2.76
FeO	14.95	9.48
NiO	.06	
MnO	.93	.06
CaO	2.32	9.70
MgO	15.97	5.93
K_2O	1.68	
Na_2O	.35	2.87
H_2O at 105°	.07	.50
H_2O above 105°	1.26	
P_2O_5	.03	.67
Total	100.09	99.82
Sp. Gr.	3.193	2.967

I. Granulitic hypersthene-gabbro. Very rich in hypersthene and biotite and poor in feldspar. Much of the latter is unstriated. Analyzed by Dr. H. N. Stokes. No. 7036.

II. Granulitic diallage-hypersthene-gabbro. Diallage much more abundant than hypersthene. No mica. Most of the feldspar striated. Analyzed by W. H. Melville. No. 8879.

Diallagic Varieties.—The great majority of the granulitic gabbros contain neither olivine nor hypersthene. These rocks consist essentially of diallage and plagioclase, or of these minerals with biotite and hornblende. The varieties without the last two named minerals are not as common as those containing them. Indeed, only three sections of diallage rocks free from biotite

have been seen, and in these the structure is slightly different from that of the typical granulitic rocks. The plagioclase in them is more or less lath-shaped and the augite grains in many cases possess idiomorphic outlines. In section M. 458 H. for instance, the pyroxene occurs in two forms, viz., in small fresh, greenish, partly idiomorphic grains that produce with the small more or less lath-shaped grains of plagioclase a granulitic aggregate, and in large altered crystals, filled with magnetite. The

FIG. 3.—Idiomorphic pyroxene in granulitic gabbro, surrounded by granulitized augite. M. 458 H. x. 30.

outlines of many of these larger grains are clearly the result of the crystallizing force, but, nevertheless, they are not sharply defined, since their peripheries are slightly granulated (Fig. 3). Within the granulated portion, however, the original contours of the crystals remain, so that the granulated peripheries are not properly granulated portions of the original crystals, as in the cases described by Professor Judd,[1] but are rather additions made by small grains adhering to the exteriors of the large crystals. In the Scottish occurrence the interiors of the grains did not assume a definite crystallographic form before the granulated pyroxene was produced. Here the homogeneous nucleus passes gradually into the granulitic portion in consequence of "Crystallization having gone on to a certain extent, while the [rock] mass

[1] l. c., Fig. 4, Pl. VII., p. 94.

was in a state of perfect internal equilibrium," and then having been concluded, after some internal movement or strain had been set up within it. In the Minnesota rock the crystal of pyroxene was completely formed before the granulated portion was added to it. The crystallization of the diallage took place in two distinct stages, first, while the rock's material was in a state of internal equilibrium, during which period the perfected crystal was formed; and, second, at some more recent period, when a change in the conditions under which the rock-mass existed afforded a favorable opportunity for the formation of a second generation of augite, which took the form of granulitic grains. The crystal above pictured is the most perfect one in the section. Others no longer possess such a distinct outline. An interior nucleus heavily charged with magnetite or black earthy decomposition products is surrounded by a clearer zone of light green pyroxene with few inclusions of any kind, and this in turn passes into the granulitic material; or a fairly clear interior may be surrounded by a zone of decomposition substance, marking the outline of the original crystal, and this be enveloped by a clear zone with its attendant granulitic periphery. In all cases, however, it is plain that the pyroxene separated from the rock-mass in two entirely distinct stages.

The second generation of diallage forming, with the plagioclase, the granulitic groundmass in which the larger grains lie, is in very light green, almost colorless grains measuring from .03 to .15 mm. in diameter. They are usually longer than they are broad, thus giving rise to short prismatic forms, on which occasionally crystal faces may be detected. They include small particles of magnetite and are themselves often enclosed in plagioclase.

The last named mineral likewise appears to be in two generations. At any rate it occurs in good-sized lath-shaped grains, and in smaller ones with badly defined rounded outlines. Magnetite is included in both varieties in large quantity.

Of the few remaining components magnetite and biotite are the most important. The former is in large irregular grains

between the diallage and plagioclase, and in small grains or particles included within them. Much of it may be primary, but most of it is undoubtedly secondary. The biotite is found principally between magnetite and plagioclase as a reaction rim around the former mineral, although in some instances it appears to replace pyroxene.

In many specimens of these rocks the pyroxene is quite fresh. In other sections the diallage has undergone a change by which hornblende has resulted. This is in the brownish-green indefinitely outlined flakes and plates characteristic of secondary hornblende. It occurs principally in the outer portions of the larger crystals, but sometimes it extends inward until it replaces their entire substance. The granulitized augite of the groundmass in which the porphyritic crystals are imbedded is also occasionally changed into hornblende, but only when in the near vicinity of the larger grains. Most of the granulitic augite is unaltered.

Biotitic and Hornblendic Varieties.—As the biotite and hornblende in the granulitic rock increase in amount the pyroxene decreases until the first two minerals begin to affect materially the character of the rock and to give it a distinctive aspect in the thin section. Sometimes the biotite occurs unaccompanied by hornblende, though this is rarely the case. It usually occurs together with the amphibole, with the latter in no inconsiderable quantity.

The biotite is in two forms, either as small plates with the general outlines of small granulitic augite grains, or in larger very irregular flakes, many of which are so closely associated with magnetite that they must be considered as having originated through its alteration. The smaller plates of the mica and much of the material of the larger ones are very probably alteration products of pyroxene. The former have the same shapes as the granulitic grains of this mineral, while the latter often seem to grade insensibly into comparatively fresh augite substance. Some of the plates surround cores of fresh diallage from which they are separated by a sharp line and some occur as well-defined plates scattered indiscriminately among the components of a perfectly fresh rock. These are probably original.

Nearly all of the hornblende that appears in these sections is quite evidently an alteration product of the augite. It is in large plates of a dirty greenish or a greenish brown color, according to the position above the lower nicol. The outlines of these plates are always ragged, and they bristle with projections that extend beyond the main mass of the plate far between the neighboring plagioclase grains. As the augite changes into hornblende, the new substance produced orientates itself uniformly until the products of a dozen or so grains become merged into a single plate, which naturally includes a large number of feldspar and magnetite grains, and of biotite flakes, provided any of these happen to have been formed before the hornblende. The structure of the plates is exactly analogous in its origin to that of Salomon's contact minerals, as it is here produced by selection of augite grains and the enclosure of those minerals that were not suitable for alteration into amphibole. When the small grains of augite are too widely scattered to affect the hornblende produced by their alteration, this substance occurs in isolated particles with independent orientations. That these little isolated grains are secondary in their origin is learned from the fact that many of the granulitic augites are partially changed into the same mineral, some only on their edges, and others throughout nearly their entire masses. In many other sections the hornblende is evidently original, in which case it has the same properties as the least decomposed of the secondary amphibole. In rock No. 7061 for instance the hornblende is more irregular in its outline than the diallage, though it usually possesses right-lined contours rather than sinuous ones. In color it is brownish green with absorption as follows: $\mathfrak{c}=\mathfrak{b}=$brownish-green$>\mathfrak{a}=$ pale yellow. Its grains occur between those of plagioclase, and they include magnetite, diallage and round or elliptical colorless inclosures like those observed within the pyroxene. Cross sections of crystals with the characteristic contours and cleavage of hornblende are not very uncommon. Although this hornblende is not unlike the secondary amphibole in others of the granulitic rocks it is not possible to regard it as due to the alter-

ation of augite or of any other mineral now occurring in the rock.

In those phases of the granulitic rocks that contain large quantities of biotite and hornblende, the former mineral is often in large plates with irregular outlines and the cellular structure that has been referred to so frequently as characteristic of the constituents of these rocks. On its basal section the mica is reddish brown. Parallel to the cleavage it is almost opaque, while perpendicular thereto it is yellow. It includes grains of augite and is often included in plagioclase. Most of the diallage in these rocks has disappeared and has been replaced by yellowish brown hornblende in grains of the same shape and size as the few augites remaining. In some sections that are otherwise quite fresh, individual augite grains are changed into hornblende often to half their extent. At some distance from their contact on either side of it the augite and the hornblende are well characterized. Near the contact their special peculiarities blend to form an intermediate substance that is neither a well defined pyroxene nor a typical amphibole. The structure of most of these varieties of the granulitic rocks is typically granulitic. There are a few cases, however, in which a departure from this structure is noticed. In rock No. 8900, for instance, the plagioclase grains are not all of nearly the same size. Large grains, with very ragged contours and small grains of the granulitic character are both common in it. The former measure between .5 and 1. mm. in length and the latter rarely more than .1 mm. No distinction as to age between the two feldspar can be made out. Sometimes the large grains seem to be younger than the small ones, and often they appear to be older. Both are more or less kaolinized and both include augite, hornblende, small colorless crystals and glassy particles. The other exceptions to the characteristic granulitic type are no more striking than is this.

Non-feldspathic Varieties.—The only granulitic rock free from plagioclase is No. 1334, which has already been referred to in another place (Vol. II., p. 824). This rock is more or less

schistose. It is composed almost exclusively of colorless pyroxene and colored hornblende. Most of the latter mineral is of the character already so frequently described, but there is in addition a little bright green amphibole fringing areas of the brownish green variety. The fresh augite and the hornblende are both principally in small rounded grains closely packed together, producing a mosaic, polarizing brilliantly between crossed nicols. Locally in the section the augite granules unite to form a fairly compact plate of this substance. In one place a large nucleus of compact augite is surrounded by a broad irregular zone of small grains of exactly the same substance. The interior is crossed by many irregular lines that divide it into a large number of small grains, but all of these are uniformly orientated, and between crossed nicols they polarize together. In the outer zone the individual grains are slightly removed from one another, and consequently each polarizes independently of all others. In a recent description[1] of this rock it was intimated that the granulitic outer zone had been caused by the fracturing of the large augite grain and the movement of the broken portions from their original positions. A more careful inspection of the section teaches that this may not be the method of formation of the peripheral granulitic zone. Movement in the rock-mass during consolidation of the granules and posterior in point of time to the formation of the nucleus has certainly been instrumental in causing the complex orientation of the granules in the outer zone, but that these latter represent fragments of an original large grain is not now believed.

D. Conclusion.

The above-described phases of the gabbro have been discussed in more detail than their petrographical interest would seem to justify, mainly because their eruptive origin appears to have been called into question.

The microscope has shown so conclusively that the rudely bedded basic and fine-grained dark rocks, interlaminated with

[1] Geol. and Nat. Hist. Survey of Minn. 19th Ann. Report, p. 196.

the quartzose bands along the northern border of the normal gabbro, are but phases of the latter rock, that a thorough field study of the relations existing between these rocks and the gabbro does not seem necessary to their correct understanding, however much it may be desirable. All the field work which has been done in the neighborhood of Akeley Lake, however, so

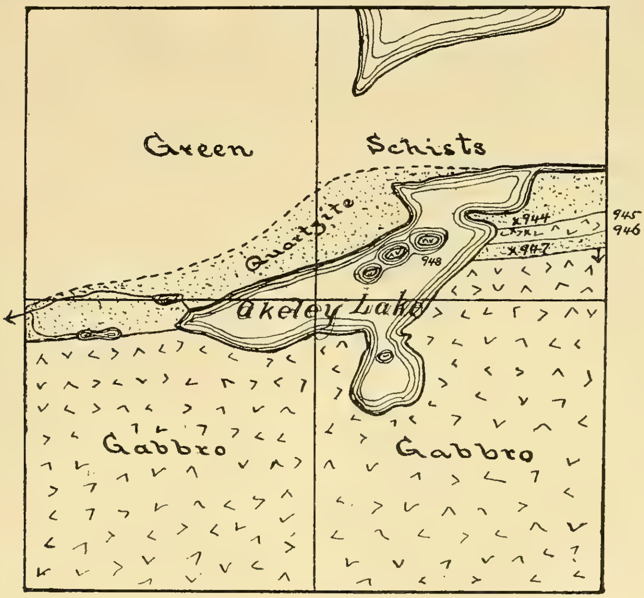


FIG. 4.—Preliminary geological map of the vicinity of Akeley Lake, Sec. 29, T. 65 N., R. 4 W., Minnesota. From manuscript map furnished by Dr. U. S. Grant, of the Minnesota Survey. Scale, 3 inches to mile.

far as it goes, confirms the conclusions of the microscope. A map of this region has kindly been furnished the writer by the Minnesota Survey through the courtesy of Dr. U. S. Grant. It is reproduced in Fig. 4.

The rock south of the lake is the normal olivine gabbro. On its northern side this is in contact with the crystallized quartz-olivine-pyroxene rocks, to which reference has already been made (Vol. II., p. 816). On the map they are marked "quartzite." Between the main masses of the "quartzite" and the gabbro a

repetition of bands of these two rocks intervenes, so that the gabbro area appears to pass gradually into the "quartzite" area. Two large bands are shown on the map, to the east of the lake, but these bands are not composed exclusively of the quartzose rock or of gabbro. The gabbro band contains on its borders small bands of "quartzite," while the large "quartzite" band is interlaminated with several narrow bands of gabbro. When thick these interbanded gabbros are similar in every respect to the normal gabbro further south, except that they may contain more hypersthene; when thin they are basic or granulitic phases of this rock.

The quartzose rocks contain a large quantity of gabbro material, such as olivine, diallage, hypersthene, etc., which can only have come from the gabbro in contact with them. The origin of these rocks has not yet been worked out.

Of the specimens indicated on the map No. 944, from the southern edge of the northern "quartzite" area is a quartzose rock saturated with gabbro material, and interbanded with narrow seams of granulitic gabbro. No. 495, near the contact between this rock and the large gabbro band, is a granulitic gabbro, with a diabasic structure in places. No. 946, from the center of this band, and No. 948, from the easternmost island in the lake, are normal gabbros containing some hypersthene. No. 947 is like No. 944.

Before concluding this discussion it seems necessary to refer to some misconceptions that have arisen with respect to the author's position regarding the Pewabic quartzite.[1] In the nineteenth report of the Minnesota Survey he describes a few specimens sent him by Professor Winchell from the vicinity of Akeley Lake. Some of these were labeled "Muscovados" and others "Pewabic quartzite," and were referred to under these names in the annual reports of the Survey. The "muscovados" were found, upon microscopical examination, to be mainly phases of gabbro, and the "quartzites" to include two distinct rocks, viz., granulitic and

[1] W. S. BAYLEY: Nineteenth Ann. Rep. Geol. and Nat. Hist. Survey of Minn. Pp. 193–210.

basic gabbros and quartzose rocks like those referred to above as "quartzites" in the account of the geology of Akeley Lake. Hence it was concluded that the "Pewabic quartzite," *as described from the Akeley Lake region*, could not be used as a definite horizon for correlation purposes, since so much of it is gabbro. This opinion is still held; but the writer may have been mistaken in his views regarding the origin of the quartzose rocks interbanded with the gabbros. None of those seen, are, in their present condition, fragmental sediments, nor can any trace of clastic grains be detected in them. Nevertheless, it is possible that they may be re-crystallized quartz rocks.

The basic layers interbanded with the quartzose ones are, however, not "tufaceous, eruptive fragmental elements,"[1] and cannot be a part of any distinct horizon to which the name Pewabic quartzite may be applied. These bands are igneous and are not chemical sediments, nor are they metamorphosed quartzites.

The main purpose of the paper referred to, however, was not the discussion of the Pewabic quartzite. It was the determination of the age of the gabbro, and upon this question it was supposed to have added some evidence in opposition to the view that the gabbro is of Animikie age, although Professor Winchell[2] was inclined to regard its evidence as favorable to that view.

The descriptions of the granulitic and basic gabbros so closely associated with the normal gabbro show that these rocks are not sediments, but are parts of the gabbro, and hence cannot be used for determining the age of the latter rock.

If the quartzose rocks with which they are interbanded are metamorphosed Animikie strata then the proof of the post-

[1] Professor N. H. Winchell: Footnote, 19th Ann. Rep. Geol. Survey Minn., p. 210.

[2] "Of course the intent of Professor Bayley's paper is to establish the idea of Professor Irving that the gabbro flood is later than the Animikie rather than near the bottom of it, where the Minnesota geologists have placed it, but its purport confirms the Minnesota geologists in their conclusions."—*Professor Winchell, in footnote referred to.*

Animikie age of the gabbro is conclusive. As further evidence on this question Dr. Grant[1] reports that in the neighborhood of Gunflint Lake "the gabbro was found to include fragments of the Animikie slates, and it also was found directly overlying and in contact with beds of the upper member of the Animikie. This gives additional proof of the post-Animikie age of the gabbro."

W. S. BAYLEY.

[1] 22d Ann. Rep., p. 77.

A PETROGRAPHICAL SKETCH OF ÆGINA AND METHANA.

PART II. PETROGRAPHICAL DESCRIPTION.[1]

Classification.—While limestones and other non-eruptive rocks occur in the region at present under description, yet they offer no special features of interest and will not be touched upon further. What will chiefly engage our attention are the eruptive rocks proper which make up by far the greater part of Ægina and Methana, with the eruptives from the neighboring and closely related localities of Poros and Kolautziki. Some space will also be devoted to the segregations found in the lavas and to the tuffs.

The eruptive rocks may all be referred to the two well defined groups of andesites and dacites, but a few words must be devoted to the classification here adopted before we begin their description.

The distinction between the two main groups, as defined by Zirkel,[2] does not depend solely on the presence or absence of quartz but on the superabundant amount of SiO_2 whether it has crystallized out or not, exactly as is the case with the trachytes and rhyolites. In the case of the rocks before us there is, as usual, some difficulty in drawing a fast line between the two; but, as a basis for the distinction I have used the percentage of silica, those rocks having over 62 per cent. being classed as dacites, those with less as andesites. As it was impracticable to have analyses made of all the specimens I have had to judge in some cases by the presence or absence of quartz grains, or by analogy and association, so that, though we may be left in doubt in a few cases as to where to place a given specimen, yet on the whole the discrimination is made with comparative ease, and the

[1] Continued from Vol. II., p. 813.

[2] ZIRKEL, Lehrb. v. Petrog. 2d ed., 1894, p. 569.

errors will not affect the general conclusion that may be drawn from the observations.

The sub-classification of these two main groups allows of more latitude, but is readily done by means of the ferro-magnesian silicates, the writer preferring this to a classification based on structure such as Rosenbusch adopts for the dacites.[1] It must be borne in mind that between some of the groups gradations occur, though on the whole there is less difficulty from this source in the present district than in many others. In the final classification then I have followed in the main that of Küch[2] for the closely similar Colombian eruptives, though my scheme differs from his in distinguishing between the augite and the hypersthene-andesites.

I divide then the dacites into: *Hornblende-Dacite; Hornblende-Hypersthene-Dacite*, and *Biotite-Dacite*.

The andesites are divided into: *Hornblende-Andesite; Biotite-Hornblende-Andesite; Hornblende-Augite-Andesite; Hypersthene-Andesite*, and *Hornblende-Hypersthene-Andesite*.

It may seem unwise to give a mixed, and from a certain point of view a subordinate, group like the last as much prominence as a chief group such as the hornblende-andesite; but, leaving other considerations aside, it must be remembered that the present classification is merely for purposes of description in this paper, and not intended for general use. It has the further advantage, in the present case, of making the petrographical groups correspond, to a large extent, with their geological and geographical divisions.

Hornblende-Andesite.—Rocks belonging to this group compose the whole of the Stavro district, *i. e.*, Mts. Stavro, Palæochora, and Spasmeno Vouno, and are found as well along the north slope of Mt. Chondos, or Mt. Dendros, and at a small hill south of Kakoperato. While these various occurrences greatly resemble each other fundamentally yet there are certain small differ-

[1] ROSENBUSCH, Mikr. Phys. II., 1887, p. 638.

[2] REISS and STÜBEL, Reisen in Süd Amerika. Geol. Stud. i. d. Rep. Colombia, I., Petrographie. 1. Die Vulkanische Gesteine von R. Küch, Berlin, 1892, pp. 18 and 19.

ences. The rocks of the Stavro district, on account of their quantity and importance, will be taken as the type and described in detail.

Megascopically they show a largely preponderating light gray groundmass with a slightly pinkish cast which is dull in luster but very compact and fine grained, there being no gas pores or vesicles. The specific gravity of the Stavro rock is 2.508, that of Spasmeno Vouno being 2.327. The latter differs slightly from the former in being of a purer gray color and with groundmass rougher in feel and not as fine grained.

Quite abundant phenocrysts are scattered through this groundmass but with no trace of arrangement in lines of flow. The majority of these are greenish black hornblende prisms from 0.5–2.0 mm. long. There are also seen a few stout, black, hexagonal prisms of biotite measuring 3–5 mm. each way, the interior of these often containing minute white grains which seem to be plagioclase. Many plagioclase phenocrysts are also present, of a dull white color and showing cleavage faces and occasionally twinning striations. In the specimens from Spasmeno Vouno are seen three or four pink quartz grains about 2 mm. in diameter, not surrounded by an augite fringe.

No segregations ("endogenous enclosures") were seen in the whole district. In one or two specimens there are yellowish green streaks colored by epidote and due to subaërial decomposition, and some of the plagioclase phenocrysts are colored yellow from the same cause. The rocks of Spasmeno Vouno are all more decomposed than those of Mt. Stavro, the best specimens from which are quite fresh.

The hornblende-andesites from the other localities differ from those just described chiefly in the greater abundance and larger size of the phenocrysts, among which also plagioclase is the most important; the groundmass resembles, as a rule, that of Spasmeno Vouno, being not very compact and rough in feel. One or two of the specimens from Mt. Chondos are decomposed and of a pinkish brown color.

Under the microscope these andesites show a groundmass

made up, to a large extent, of colorless or very pale brown glass base, this being much more abundant in the Spasmeno rock than in that from Stavro. In this base are strewn quite abundant plagioclase lathes[1] and small colorless microlites, some of which seem to be augite, many small magnetite grains, and (especially in the Stavro rocks) much brown "dust" in streaks and patches. A flow structure is developed among these smaller constituents, which is especially well marked in the Spasmeno rocks, where also the "dust" is almost entirely absent. There are also to be reckoned among the groundmass constituents a number of small plagioclase crystals and green hornblende prisms.

The discrimination between the phenocrystic and the groundmass plagioclase is quite easy, as the latter is almost always in the shape of small clear lathes, while the former is in much stouter crystals and generally with inclusions. The plagioclase phenocrysts are of fair size, and, under the microscope, seem quite fresh and unaltered. The stout crystals show the usual planes and very few fracture surfaces are to be seen. Twinning lamellæ, in nearly every case according to the albite law, are common and the extinction angles of 29°–30° 30′ on *c* (001) indicate that we have here a bytownite of about the composition $Ab_1\ An_4$, though in all probability other members of the series are present. Such a basic plagioclase is unusual for hornblende-andesite whose feldspar is generally labradorite or andesine, and I very much regret that the lack of proper facilities in Venice, where this paper was written, prevented the examination of the feldspar by other methods. The small lathes also belong to the bytownites, but at the end of the series richer in albite. Zonal structure is quite frequent.

Inclusions are very common in the larger crystals and in the great majority of cases are of generally clear brownish glass, occasionally dusty, and frequently holding a bubble. In many cases these glass inclusions are so numerous that they form a

[1] The term "lathes" is used for the larger, but still small, long groundmass crystals (especially of feldspar), while microlites are the smallest in size and in many cases of an indeterminable nature.

sort of "network" of the plagioclase, the meshes being of glass. This "net" usually forms a core of the same shape as the crystal with a narrow, clear, inclusion-free zone of plagioclase surrounding it. In other cases there is a central core of clear feldspar, then a "network" zone, and finally an outer clear border. Belowsky observed similar inclusions in the feldspars of andesite from West Ecuador,[1] and they are not infrequent elsewhere. Besides these glass inclusions some small clear hornblende crystals, magnetite grains and apatite needles are also to be seen as inclusions in the feldspar.

One of these apatite inclusions which is of special interest consists of a slender prism with low pyramidal terminations, .025 mm. long, from one side of which projects a smaller prism at an apparent angle of 47°. This must be regarded as a twin and identical with the apatite twin from North Carolina[2] described by me, with twinning plane *s* $(11\bar{2}1)$ and the angle between the *c* axes of 68° 28′. The lesser angle in the present case is accounted for by the fact that the twin does not lie with the plane of its two axes parallel to that of the section, as is seen on the use of higher powers. This occurrence is interesting since it serves to confirm the view that the first described case was a true twin and that the plane *s* $(11\bar{2}1)$ is a twinning plane of the species.

The hornblende of these andesites, which occurs in well shaped, though often broken, crystals (the uncommon plane *a* (100) being often largely developed) is noteworthy on account of its color. This is a light, rather bright, olive-green, the pleochroism being very strong; $\mathfrak{c}$ dark olive-green, $\mathfrak{b}$ olive-green, $\mathfrak{a}$ pale yellowish green. This color is characteristic of the hornblende of all this group, with the exception of one specimen from Mt. Chondos which seems to have undergone decomposition to some extent. Here the hornblende is of a dark or brownish green color, and the very strong pleochroism is: $\mathfrak{c}$ dark orange-

[1] Reiss and Stübel, Reisen in Süd Amerika. Das Hochgebirge d. Rep. Ecuador I. Petrog. Untersuch. I. West Cordillers, Tulcan bis Escaleras Berge von M. Belowsky, Berlin, 1892, p. 28.

[2] Am. Jour. Sci., XXIII., 1887, p. 504. *Cf.* Dana: Mineralogy, 1892, p. 767.

red, 𝔟 dark red-brown, 𝔞 light yellow-green. In this case it must be noted that some of the hornblendes are of that dark red color which, as Belowsky[1] has shown, is produced by heating the green variety. The occurrence of green hornblende in the andesites is rather unusual, the color being generally brown. As is well known the green color is characteristic of the propylites, but the present rocks show none of the well marked features of this group, and are in every other way typical hornblende-andesites. The extinction angle is 11°.

The hornblende is in every case, except that mentioned above, perfectly fresh and unaltered, the dusty edges of some of the crystals, which look at first sight like incipient alteration, being seen on closer examination to be due to overlapping layers of the dust-laden groundmass. Zonal structure is occasionally seen, some of the crystals having the commonly observed darker green core. Inclusions are not common and small, though of considerable variety; small crystals of biotite, augite, plagioclase and magnetite, with an occasional zircon or spot of brown glass, having been noted. The distinction between the phenocrystic and the groundmass hornblende is hard to draw as they grade into each other with no difference of habit.

Augite is not abundant in these rocks, though occurring here and there in small crystals, clear and almost colorless. Intergrowths of this with the hornblende are not unusual, in one case the augite occupying the center and the hornblende forming the outer part of the mixed crystal; while in other cases one end is augite and the other end hornblende. A very few sections of biotite were seen in the slides; they are greenish gray, quite fresh, and carry inclusions of plagioclase and magnetite.

Magnetite is quite abundant in the form of fine grains in the groundmass as well as larger crystals up to 2 mm. in diameter. These last not infrequently show inclusions of plagioclase, apatite and zircon, and even, as in one case, have grown around the present groundmass. Many of these larger crystals show a coppery brown luster by reflected light, and, on the edges and

[1] Belowsky. Op. cit., p. 37.

in the thinnest spots, a granular structure, the grains being semi-transparent, of a chestnut-brown color and isotropic between crossed nicols.

The fresh appearance of the rock and the crystals, and the absence of a surrounding border of brown limonite, seem to preclude the idea that their appearance is due to weathering, though they somewhat resemble the limonite pseudomorphs after magnetite observed by von Lasaulx[1] in some altered basalts from the Auvergne. In color and physical characters the grains bear a great resemblance to the crystallites in the Bobenhausen tachylyte[2] which Zirkel[3] holds to be an extremely ferruginous glass. It may be, then, that these large magnetite crystals are in reality pseudomorphs of such a glass after the original magnetite, due to the combination of the latter with the magma.

A curious fact is that the majority of these larger magnetite crystals are accompanied by perlitic cracks in the groundmass, which surround the magnetite at a short distance from it either completely or partially, there being sometimes only one and sometimes several such cracks about each grain. These cracks are not met with elsewhere in the groundmass, nor do they surround any of the other minerals, and their formation may be connected with the brown coloration and granular structure just described. It must be noted that the groundmass between the cracks and the magnetite grains, quite up to the latter, is entirely normal and identical in color, structure, etc., with that elsewhere.

In addition to their green hornblende these andesites are specially marked by the presence of tridymite, which is very common, especially in the rocks of the Stavro district. This occurs in small irregularly-shaped masses or round rosette-like clusters showing the usual shingle structure, or in radially arranged spherical aggregates, about 0.1 mm. in diameter. As they often occupy the sides of small cavities they seem in part to be of secondary origin, but this is not at all certain.

[1] Neu. Jahrb., 1870, p. 695.

[2] *Cf.* VOGELSANG, Die Krystalliten, Bonn, 1875, p. iii., and Pl. XIV., Fig. 1.

[3] ZIRKEL: Basalt Gesteine, Bonn, 1870, p. 182, ff.

The above description will apply on the whole to the hornblende-andesites from the other localities, though in these last the phenocrysts are much more abundant. In two of the specimens, from Mt. Dendros and from the ridge southwest of the monastery, the groundmass is markedly spherulitic. The spherulites belong to Vogelsang's globospherites, being rounded aggregations of brownish dusty globulites and some trichites, arranged so as to give to the spherulite a fine radially fibrous structure. Surrounding this fibrous granular center, which has no action on polarized light, is a narrow border of clear, colorless isotropic glass substance. The groundmass of these spherulitic andesites is very vitreous, and with many perlitic cracks.

Biotite-Hornblende-Andesite.— The only representative of this group is the rock which forms the small promontory on which stands the town of Poros. Megascopically the specimens resemble much more the lighter hornblende-augite-andesites than the rocks just described, having a fine-grained gray groundmass containing very many plagioclase crystals and small hornblende needles. In this — generally arranged in lines of flow — are very numerous phenocrysts, chiefly of white plagioclase with stout black hornblende prisms and many biotite tables ; grains of quartz are very rare. Much of the rock is partially decomposed and then assumes a reddish brown color, the plagioclase being tinged with yellow, and the biotite tables acquiring a brilliant submetallic bronze-luster resembling that of phlogopite.

Under the microscope they show a groundmass of largely preponderating colorless glass base, containing many small microlites chiefly of plagioclase, with plagioclase lathes, small, fresh, greenish brown hornblende crystals and but little magnetite Flow structure is beautifully developed in the groundmass, and segregations are quite frequent.

The phenocrysts of hornblende are of the same greenish brown color and perfectly unaltered ; in the decomposed specimens however being decidedly brown, with no traces of a green tone, but still remaining perfectly clear. Biotite crystals are quite common, of an olive-green color when unaltered, but in the

less well preserved specimens of a reddish brown or brilliant orange. Some of them are bent and show frayed ends. The plagioclase calls for no special remarks; twinning lamellæ are common and the extinction angles of nearly 30° show that it is a bytownite. A few clear colorless augite crystals are also present.

The rock from this locality has been described by R. Lepsius[1] who states that the feldspar is orthoclase, does not mention the very abundant hornblende, states that the rock contains 60.21 per cent. of SiO_2, and calls it a trachyte and the same rock as that which occurs at Kalamaki and Kolautziki, which last, as we shall see later is not the fact. He seems to have examined but one hand specimen, and that more or less weathered. My study of the rock *in situ* and of the three specimens brought back with me does not bear out his view that it is a biotite-trachyte. The feldspar is all, with scarcely an exception, undoubtedly plagioclase, hornblende is abundantly present, and the slightest comparison of the specimens in my possession show that the Poros and the Kolautziki rocks are quite different. It is possible that Philippson may have collected a specimen quite different from mine, but if so it must be of a subordinate facies and not from the main mass of the Poros dome. In the few hours which we spent at Poros I went over most of the small hill and found only the rocks such as have been described above. The main body of the rock of Poros must then be with certainty regarded as a biotite-hornblende-andesite and not as a trachyte.

Hornblende-Augite-Andesite.—The chief rocks of the central part of the island of Ægina belong to this group as it makes up the main part of Mts. Chondos, Pagoni, Dendros and Gaiapha, with probably many of their outlying spurs.

Megascopically they differ considerably from the rocks to the north and south of them, showing a highly porphyritic structure with very numerous phenocrysts, the latter being in some cases so abundant as to give the rock almost a granitic appearance. The phenocrysts are almost entirely plagioclase, with few hornblende prisms and still fewer biotite tables, no quartz grains

[1] PHILIPPSON. Op. cit. p 604, *cf.* ZIRKEL, Petr. p. 258.

being seen in any of the specimens. The groundmass is almost without exception dark gray, in some of the Mt. Chondos specimens almost black, quite compact and occasionally with a subgreasy luster. The rock near the tuff at the west end of Mt. Chondos shows a banded structure of alternate dark and light gray streaks,which run almost vertically ; they are best brought out on slightly weathered surfaces.

The only exception to the above general description is the hornblende-augite-andesite specimen from a small hill or ridge southeast of Kakoperato, which is much less compact in texture, lighter in the color of the groundmass, and shows a great many phenocrysts of hornblende.

All these andesites show a great tendency toward decomposition, becoming dull, more or less friable, and of a light reddish or purple color. Endogenous enclosures are quite common in the rocks of this group and will be described later.

Under the microscope the groundmass of these rocks is seen to be not typically hyalopilitic, but consisting of a glass base which is either colorless or brown according to the megascopic appearance of the rock, containing numerous microlites of plagioclase and augite with many magnetite grains and very much fine globulitic "dust." In the groundmass are also seen many larger plagioclase lathes, with small, stout, colorless augite crystals, and fewer small hornblende crystals, many of which are quite fresh and of a yellow-brown color, while others are altered to a dark opacitic mass either on the edges or completely. Here again while the distinction between the groundmass and phenocrystic plagioclase is easy on account of their diverse habits, as in the Stavro rocks, in the case of the augite and hornblende the line of demarkation cannot be sharply drawn, and the distinction is almost entirely a question of size, though the difference in the amount of alteration in the small and large hornblende crystals is of some assistance.

Augite occurs in not very large, usually well shaped crystals, showing the common planes of a clear and extremely pale brownish yellow color, so faint as to be almost colorless. In

some of the more decomposed specimens they are colored yellow or reddish brown on the edges. No pleochroism is to be observed, and the extinction angle is decidedly high, in many cases reaching or surpassing 45°. Hour-glass structure is not uncommon, though never well developed. Though the crystals are as a rule simple, yet twins, generally with the twinning plane *a* (100), are to be noted; and in some cases interpenetration twins, of two prisms crossing at angles of about 76° and the clinopinacoids being parallel. These apparently have the twinning plane *c* (001), and resemble the augite twins described by Elich[1] in andesites from Ecuador.

The crystals are frequently grouped in clusters of irregular shape, and with no definite arrangement of the component crystals, somewhat resembling in structure, but not mineral composition, the clusters of Judd's glomero-porphyritic structure.[2] These again sometimes assume the form of rings of augite crystals (sections of spheroidal shells), which surround a nucleus of clear, colorless substance which generally shows perlitic cracks and only rarely exhibits a faint double refraction. This is without doubt glass, and in the few cases where it acts on polarized light the effect may be caused by a state of strain due to the growth of the augite shell. Projecting into this glass nucleus from the inner edge of, and at right angles to, the augite ring, are small colorless or greenish prismatic crystals, which present all the characteristics of augite. They resemble the augite fringes often seen around enclosed quartz grains and may be of secondary origin.

The hornblende of these andesites belongs to the brown variety and megascopically much resembles the so-called basaltic hornblende, though the color is blacker and the surfaces more glistening.

Microscopically they are seen to be larger than the green

[1] Reiss and Stübel. Reisen in Süd America. Das Hochgebirge, I. Rep. Ecuador, I. West Cordillers iii., atacatzo bis liniza von E. Elich. Berlin 1893, p. 157, Pl. iii., Fig, 4.

[2] Judd. Q. J. Geol. Soc. XLII. 1886, p. 71.

hornblendes of the hornblende-andesites or than the augite crystals accompanying them, and to have been originally well shaped stout crystals, without the orthopinacoid. The color is a pale yellow-brown, with strong pleochroism; $\mathfrak{c}$ yellowish brown, $\mathfrak{b}$ yellowish brown, $\mathfrak{a}$ colorless, the absorption being $\mathfrak{c} \geq \mathfrak{b} > \mathfrak{a}$. In some of the hornblende-augite-andesites of Mt. Pagoni an intermediate type is seen, of a greenish brown color, which, however, resembles more the brown than the green variety. The extinction angle of the brown variety is lower than that of the green, varying from $5°–6° 35'$—a fact quite in accordance with the observations of Belowsky, to be mentioned later. Inclusions are not common.

This brown hornblende, as has been so often noticed, is decidedly prone to alteration. While most of the small crystals which occur in the groundmass are either quite fresh or only altered on the edges, the larger crystals, even the largest, which may be ten or many more times the diameter of these smallest ones, are entirely altered (or with only a small unaltered core) to a very fine-grained almost opaque, black mass of augite and opacite (magnetite) grains. The further stage of alteration to a more coarsely granular augite-magnetite aggregate is not generally seen in these rocks. Notwithstanding their alteration the original sharp outlines of the hornblende have been excellently preserved.

This alteration is so familiar and has been so often described that it is unnecessary to dwell upon it here at any length. One or two points call however for special mention. The presence of the small, unaltered crystals along with much larger altered ones points to the conclusion that not only were the large ones altered at a quite early period, but that the small ones were formed subsequently to, and under different conditions from, the alteration of the larger ones.

I observed also in many cases of juxtaposition between hornblende and feldspar that the presence of the feldspar had no effect on the alteration, this being as great at the surface of contact as along the free sides of the hornblende crystal. This differs some-

what from the observation of Küch[1] that hornblende in contact with microfelsitic groundmass was unaltered, while next to vitreous groundmass it had been altered, this being seen even in the same crystal.

A few words in regard to the difference between the brown and the green varieties of hornblende. Belowsky,[2] on the basis of some very valuable and interesting experiments of his own, puts forward the view that the brown is chiefly produced by alteration of the green "through the action of heat, in which oxidation was possible." Against this view must be brought up the fact that here in Ægina we meet with both varieties, but never in the same rock species. The green is characteristic of the *pyroxene-free* hornblende-andesites, and where this has undergone alteration, as in the case from Mt. Chondos, described on page 25, the resulting form of hornblende is quite different from the brown variety just described, which is the characteristic hornblende of the *pyroxene-bearing* andesites. This correlation of almost colorless pyroxene and brown hornblende, which is well established in the rocks before us (and, I may add, in the closely analogous augite-andesites of Smyrna and biotite-andesites of Pergamon), shows that the formation of the different varieties of hornblende is dependent on the different chemical constitutions of the magmas, and on the different conditions, which in one case determined the crystallization of the ferro-magnesian molecules as pyroxene and brown hornblende, while in the other they crystallized out as green hornblende, with or without biotite, and with little or no augite.

That the green hornblende on heating assumes the color and extinction angle of the basaltic hornblende is not to be denied, but in view of the facts above mentioned, and the vague and unproven character of the difference of heat conditions in the formation of the different varieties of hornblende, it is surely too much to infer from this fact that the brown hornblende is always derived from the green by alteration of the latter, and cannot have an independent origin and existence of its own.

[1] KÜCH. Op. cit. p. 55. Pl. V. Fig. 6.
[2] BELOWSKY. Op. cit. p. 37 ff.

It must further be remembered that the green hornblende was itself formed and existent in a magma at a temperature undoubtedly much higher than that of the simple Bunsen burner employed by Belowsky; but whether in the absence of oxygen or not we cannot perhaps say, though in view of the well established presence of water in most lavas and its probable dissociation at the high temperature of the liquid lava in the conduit oxygen may reasonably be supposed to have been present. At any rate, in the case of two lavas erupted under such similar conditions as those of Stavro and Chondos there is no ground for assuming that the latter was at a higher temperature than the former,[1] or that the one was oxygen-free and the other not. Again, it is difficult to explain by Belowsky's theory the presence in the same specimen of crystals of both varieties, which has been frequently observed, while if we grant to each variety a separate existence, this fact is easily explicable on the basis of the frequent presence of streaks (*Schliere*) in molten magmas, and their consequent want of homogenity in chemical composition.

The plagioclases of the andesites show the same difference between the phenocrysts and the groundmass crystals as in the preceding rocks. The phenocrysts are usually quite clear, and while glass inclusions, often with bubbles, are common and frequently zonally arranged, they seldom show such well developed net forms as have been described above. The phenocrysts show much zonal structure and many twinning lamellæ, which, giving extinction angles of 33° and 34°, show that they are of anorthite, while the smaller lathes, giving angles of 22° to 24°, are of bytownite.

Phenocrysts of biotite are not infrequent, and are in most cases entirely altered to an opacitic aggregate similar to the hornblende. Magnetite is abundant, but calls for no special remark.

Hypersthene-Andesites.—These rocks are characterized by the abundant presence of orthorhombic pyroxene, hypersthene, which

[1] As the Chondos rock seems to be more basic than that of Stavro, it is even probable that its temperature on eruption was less than that of the latter; this would also hold good for the brown hornblende-bearing hypersthene-andesites and the green hornblende bearing dacites.

is often accompanied by augite, occasionally to such an extent that it is difficult to decide whether a given specimen ought to be called a hypersthene-augite-andesite, or an augite-hypersthene-andesite. With one exception, however, it seemed better to group them all under the heading above, especially since the great majority of hypersthene-andesites elsewhere do carry more or less augite, while many augite-andesites are entirely free from orthorhombic pyroxene. The rocks richer in augite will be known as augite-hypersthene-andesite, while those which are quite free from, or very poor in, augite will be called hypersthene-andesite proper. The reason for making this distinction is the greater inasmuch as it corresponds quite exactly with the geographical distribution of the two varieties. The one exception mentioned above is that of a rock entirely free from hypersthene, which is hence a true augite-andesite, and will be described in its proper place.

In some of these rocks, notably in the products of the latest eruption at Kaimeni, hornblende is present in considerable quantity, and as the presence of this hornblende is correlated with structural and other characteristics, these specimens will be described later as hornblende-hypersthene-andesite.

The list of localities at which hypersthene-bearing and hypersthene-andesites occur has been largely increased in the last few years, and their occurrence here is not at all surprising when it is recalled that they occur abundantly at Santorini and Milos and at Erimomilos which are on the same volcanic fracture line. This point will be referred to later.

Hypersthene-andesite proper is found only on Methana, at the top of Mt. Chelona, at and above the acropolis of Methone, around the small harbor of Vathy on the west coast and at one point on the northeast coast. The augite-hypersthene-andesites make up the main mass of Mt. Oros and Mt. Kouragio on Ægina, while the augite-andesite proper is found at Agio Somatos near the Hellenic ruins. These sub-groups resemble each other so much and shade into each other so gradually that they may be described together.

Megascopically they are compact, fine-grained rocks of a rather dark, slightly bluish gray color, the groundmass showing to the naked eye comparatively few small phenocrysts of dull white plagioclase with, at Chelona, a few hornblende needles, and at Oros and Mt. Kouragio a very few rounded colorless quartz grains. They present, on the whole, a decidedly phonolite-like appearance, the resemblance being heightened by the lamellar structure seen on the top of Mt. Oros and at Agio Somatos, and by the sound which many of them give on being struck with a hammer, notably the rock from the south end of Mt. Kouragio. The augite-andesite of Agio Somatos differs slightly from the others in being rather granular in structure, and containing more slender hornblende needles. These rocks do not decompose readily and are quite fresh, except in the case of two specimens from Mt. Oros, which are reddish brown in color.

Under the microscope these rocks show an abundant, often hyalopilitic groundmass, with flow structure well marked; the glass base, which is clear and colorless, except in the Mt. Kouragio rocks where it is light brown, being in relatively small quantity. This glass base seems to be more abundant in the hypersthene-andesites than in the augite-hypersthene-andesites, in one or two of the latter from Mt. Oros the groundmass being almost holocrystalline, with only traces of glass, and in those from Mt. Kouragio the groundmass being rather basaltic with many lathes of plagioclase and hypersthene, and very little interstitial glass base.

The microlites and small crystals of the groundmass are mainly hypersthene, with fewer of plagioclase, many magnetite grains, and in the augite-hypersthene-andesites very many small, approximately equidimensional crystals of nearly colorless augite.

The small hypersthene needles vary in length from 0.02 to 0.1 mm., their diameter being as a rule about one-fifth of the length. They all have parallel extinction, show low domal or pyramidal terminations, and are generally cracked transversely. They are clear and almost colorless, of a very faint greenish

tinge, with feeble but marked pleocroism, || c pale greenish gray, ⊥ c pale yellow. The hypersthene is the most easily decomposable constituent of these rocks, perhaps owing to the large amount of FeO, and in the more altered rocks (such as those of Mt. Oros) they have almost entirely disappeared, and are only represented by red and brown rectangles and patches of ferrite, or other ferruginous decomposition products.[1]

The plagioclase lathes and crystals of the groundmass show few planes and are usually rectangular in outline. They are either single crystals or simple twins, very few showing multiple twinning lamellæ. As they possess extinction angles of 28° to 31° they belong to the bytownites richer in lime, or even to the anorthites.

A striking characteristic of the hypersthene-andesites proper is their extreme paucity in phenocrysts, especially of the ferro-magnesian silicates. Plagioclase phenocrysts occur, but not abundantly, both megascopically and microscopically, but phenocrysts of pyroxene, hornblende or biotite are almost entirely lacking; a circumstance which, together with the facts that hypersthene is abundant in the groundmass, and that the small plagioclase lathes are apparently richer in lime than the phenocrysts, forms another occurrence, in addition to the many already noted, which are not in accordance with Rosenbusch's law that as crystallization proceeds the remaining magma becomes more acid.

Phenocrysts are, however, much more abundant in the other sub-group, and consist chiefly of augite in not well shaped, clear, and almost colorless crystals. Hypersthene in prisms up to 0.8 mm. in length also occurs. The presence of augite seems to have determined, or to be correlative with the presence of hornblende which is almost or quite entirely wanting in the hypersthene-andesites, but rather abundant as phenocrysts in the other group. Originally of a brown color it is invariably altered to an augite opacite aggregate, which is generally quite fine-grained and surrounded by an outer zone of colorless augite with some plagioclase.

[1] *Cf.* Felix and Lenk: Beitr. Geol. Pal. Rep. Mexico, Leipzig, 1890, I., p. 91.

In the Mt. Kouragio rocks, however, it is more coarsely granular and apparently little coherent, as the original crystal outlines are quite lost and the granular masses rounded and washed away by the moving magma.

The plagioclase phenocrysts are of good size and show many more planes than the smaller groundmass crystals. They seldom show twinning lamellæ and the one case where measurement was possible gave an extinction angle of 25°. They bear as inclusions small hypersthene and apatite needles and spots of glass. Some of them show a peculiar core composed of a micropegmatite of what may be either two different feldspars, or particles of the same feldspar, but oriented in two different directions.

In the rock which forms the small hill of the Methone acropolis there are present quite numerous phenocrysts of olivine which can also be seen with the naked eye. These are rather irregular in shape and often broken, though showing traces of crystal faces. They are colorless and quite fresh except on the edges, where they are generally colored bright yellow through incipient decomposition. Such an olivine-bearing hypersthene-andesite also occurs in one specimen from near Vathy Harbor, and from the west slope of Mt. Oros. The last specimen differs from the other rocks of the district in being of a pale brown color, very compact, with subresinous luster and with numerous phenocrysts.

Hornblende-Hypersthene-Andesite.—This has a special interest as it forms the material poured out by the eruption of *ca*. 250 B. C., and hence represents the latest eruptive product of the region. It is also represented by specimens from a loose block on Mt. Chelona and from near Agios Georgios on the northeast coast. The Kaimeni rocks are, however, of the most importance and the following description applies chiefly to them.

They are not very compact rocks, containing numerous pores and in some of the specimens assuming a quite scoriaceous character. They are highly porphyritic, showing, when fresh, a light gray, fine-grained, but dull and not very compact groundmass, with many phenocrysts of plagioclase and black hornblende,

very few biotite tables and still more rarely quartz grains. The scoriaceous specimens are decomposed and have become rather friable and of a dark reddish brown color. The specific gravity was found to be 2.44 in the freshest specimen.

Microscopically they show a hyalopilitic groundmass of colorless glass base with very numerous, almost or quite colorless, hypersthene and fewer plagioclase lathes. Larger, but still extremely small plagioclase and hornblende crystals, together with a few colorless augites, are also present in the groundmass.

The hornblende which occurs as large phenocrysts is generally prismatic, and of a brownish green color, quite fresh and free from alteration. It contains some inclusions of magnetite, plagioclase and a few biotites of large size and is itself inclosed partially by the largest plagioclase phenocrysts. These latter which, judging from the extinction angles on *c* (001) of 35°–38°, are anorthite, are quite fresh but contain many inclusions, chiefly of brownish glass with bubbles, and in one case of very many small flakes of biotite. A few phenocrysts of the latter are also seen, and good-sized grains of magnetite are abundant.

The hornblende-hypersthene-andesites from the other two localities much resemble the above, that from the top of Mt. Chelona differing chiefly by its more typical hyalopilitic structure, the absence of transition forms between the phenocrystic and groundmass crystals and the more vivid green of the hornblende.

Hornblende-Dacite.—This composes the two hills at Anzeiou and Kakoperato in the Oros District on Ægina which seem to be later flank eruptions of the main Oros outflow. The Anzeiou rock is light gray, rather compact and quite free from pores but rough in feel. The groundmass is fine-grained with numerous small hornblende needles. Phenocrysts are very abundant, chiefly white plagioclase crystals with some larger black hornblende prisms and many slightly pink quartz grains, generally rounded, but here and there showing a bipyramidal form, unaccompanied by an augite fringe.

The Kakoperato rock differs somewhat from the other, the phenocrysts which are the same as in the preceding being much

less numerous, though larger, and arranged often in lines of flow. The groundmass is very compact, of a darker, bluish gray color and sub-greasy luster, containing some hornblende needles. The enclosures in this rock, which are very numerous and striking, will be described later. With this Kakoperato rock must be classed the rock near Agio Vesili on the west coast of Ægina, on the ground of its general appearance, though no analysis of it was made and quartz grains are not nearly as abundant as in that just described.

Under the microscope the slides of these occurrences show much the same features.[1] The hyalopilitic groundmass is largely predominant, the glass base being colorless (with no perlitic cracks), and the microlites (which are largely feldspar) showing a beautiful flow structure, but being more abundant in the Kakoperato than in the Anzeiou specimens. Crystals of hornblende and plagioclase and grains of magnetite are also rarer in the groundmass of the former while abundant in the latter. Many of the microlites and lathes of feldspar in the Kakoperato dacite are untwinned and show parallel extinction which points to the presence of orthoclase, belief in which being strengthened by the comparatively large quantity of K_2O shown on analysis. It is noteworthy that neither in these nor in any of the other dacites was quartz met with as a groundmass constituent.

The phenocrysts are chiefly hornblende and plagioclase, only a few quartz sections being found in the slides. Magnetite is present, though not abundantly, in rather large, well shaped grains which must be classed rather with the phenocrystic than with the groundmass constituents.

The hornblende which occurs only as phenocrysts is in small but well shaped crystals, often broken. In color they are brownish green (that of Agio Vesili is greenish brown) and quite fresh and unaltered. Rare inclusions of plagioclase, augite, and magnetite are found. In general character and habit they much resemble the hornblendes of the Stavro rock, though the color is more inclined to brown.

[1] On the whole the slides much resemble those of the dacite from Lassen's Peak in my possession.

The large plagioclase phenocrysts are quite fresh and clear and many show a "network" core of glass. Twinning lamellæ are not very common, and, as the angles observed were small, the phenocrysts are referable to labradorite, though in some cases they seem much more basic.

The few quartz sections are rounded and irregular, perfectly clear but much cracked and with few inclusions of glass. One small perfectly hexagonal section was seen. A few small colorless prismatic augite phenocrysts were noted as well as some dark green biotite tables, one of which contains a colorless zircon.

Hornblende-Hypersthene-Dacite.—It would be more in accordance with Zirkel's definitions to call these rocks quartz-pyroxene-andesites since he reserves the name dacite for the more acid or quartz-bearing hornblende or biotite-andestites.[1] On the other hand Rosenbusch[2] does not put these limits on the dacites, but includes among them very acid or quartz-bearing pyroxene-andesites. I am inclined to favor his view since the presence or absence of quartz or superabundant silica seems to me a consideration of much more weight than the nature of the ferro-magnesian silicate, and this, together with the presence of *green* hornblende in the most typical specimens, has decided me in giving them the name they here bear; they being called as they are owing to the greater abundance and importance of the hypersthene over the hornblende, none of the latter appearing as a groundmass constituent.

These rocks are the most abundant of any species on Methana, most of the mountain masses around Mt. Chelona being formed of them. Specimens were collected and examined from near Vromo, from the ridge south of Mt. Chelona, Mt. Chorsa to the northwest of Chelona near Panagia on the northwest coast, and from the neighborhood of Kosóna, both near the town and between it and Mt. Chelona; and, further, my notes show that the rock along the coast between Kosona and Vromo

[1] ZIRKEL. Op. cit. II., p. 569.

[2] ROSENBUSCH, Mikr. Phys. II., 1887, p. 634.

Limni are the same as at the former place; so that it is seen that the whole southern part of the peninsula (with the exception of the district around Methone and Megalo Chorio), with much of the northwest, north and east are of these rocks.

These do not show as much quartz as the other dacites, that from near Panagia especially being quite free from it, though its high silica content (64.83 per cent.) shows that it belongs here. Megascopically they much resemble the dacite of Anzeiou, being not very compact, light-gray rocks with very numerous phenocrysts of plagioclase and hornblende, and fewer colorless or pinkish quartz grains. The Panagia specimen is much more compact and finer grained than the others, and phenocrysts are smaller and less abundant. Endogenous enclosures are not rare, especially in the rock about Kosona.

Under the microscope there are seen to be three distinct types. The Kosóna specimens resemble much the hornblende-dacite of Anzeiou, the groundmass being typically hyalopilitic with colorless glass base. The hornblende is bright olive-green and perfectly fresh. Hypersthene, besides composing the great majority of the groundmass microlites, occurs in good-sized prisms as phenocrysts, which show all the optical characters already mentioned. Magnetite also occurs in large and small grains, but is rare as a true groundmass constituent. Some small colorless augite crystals are also seen. The plagioclase, which occurs chiefly in large poorly shaped phenocrysts, many with glassy "net" cores, shows many twinning lamellæ; and the extinction angles of 25° and even less show that it is a bytownite rich in soda. They contain very many apatite needles. Biotite is very rarely seen in the slides, one large, clear, greenish gray prism being much corroded, and altered at the edges to a very coarse granular mixture of augite, plagioclase and magnetite. This alteration had chiefly taken place in the zone of the prisms and pinacoids, the basal plane being sharp and quite fresh.

The second type is that presented by the specimens from the southern and western parts of Methana (with the exception of the Panagia specimen). These are characterized by a very dusty

brown groundmass, the base being colorless glass which is filled with an infinite number of grains of "dust" and small microlites, generally short, stout and rarely long (as usual). These microlites are chiefly augite and hypersthene, little plagioclase being represented. Besides these microlitic constituents there are small lathes and rectangular sections of plagioclase, small augite and hypersthene crystals and some magnetite.

The hornblende phenocrysts in these rocks are yellowish brown in color, and often altered on the outer edges to an augite opacite aggregate. Hypersthene crystals are common, but not as large as in the preceding type. In one specimen, which shows signs of decomposition, they are either entirely or partially changed to rusty or reddish brown secondary products. The plagioclase, whose sections are generally rhombic or rectangular, is similar to that of the preceding. A few clear, corroded and cracked quartz grains are seen.

The third type is only represented by the Panagia specimen, which also differs from the others megascopically. The groundmass here seems to be chiefly microfelsite with little or no glass. In the microfelsitic base are many minute magnetite grains, and flecks and microlites of feldspar, part of which may be orthoclase, as indicated by the parallel extinctions. As the percentage of K_2O is small, however, it seems more probable that this is labradorite, or oligoclase. Hypersthene is not abundant in the groundmass.

The phenocrysts are not numerous and consist of brown hornblende, altered as before described, with some plagioclase and hypersthene, which call for no special comment. There are numerous spots of tridymite, which seem to be an essential and not a secondary constituent.

It must be remarked that the position of this Panagia rock is an uncertain one on the whole, and I would call it a trachyte were its percentage of K_2O not so very much lower than that of any other trachyte analysis.

Biotite-Dacite.—This dacite, whose occurrence is described on page 806, Vol. II., is only found on the mainland, and all the

specimens examined come from the railroad cutting near the hamlet of Kolautziki. A short petrographical description by Dr. R. Lepsius, which will be referred to later, will be found on page 604 of Philippson's "Peloponnes."

The specimens show a fine-grained, but not very compact, very light gray or light brown groundmass which contains many minute black biotite flakes and feldspar and quartz grains. In this are thickly scattered larger phenocrysts of colorless feldspar, small biotite tables and grains or bi-pyramids of pink or amethystine quartz, which on the weathered surfaces have entirely lost their color. These crystals do not show much definite arrangement in lines of flow.

Under the microscope they show a highly vitreous groundmass traversed by numerous perlitic cracks, and containing few microlites, but flow streaks of brown or greenish dusty matter. In the groundmass also lie many small flakes of olive-green biotite, with some small plagioclases and still fewer small quartz grains which are arranged in lines of flow. Hardly any magnetite is present.

The phenocrysts are of biotite, quartz, and feldspar. The first are not very large hexagonal tables, olive-green when fresh, but banded or mottled with reddish brown in the decomposed specimens. They are very poor in inclusions, only a few plagioclases and zircons being thus met with. Clear, colorless quartz grains are common, generally with rounded outlines, though occasionally showing crystallographic boundaries. They are quite free from inclusions, no glass being noted and only a few colorless zircons.

The feldspar phenocrysts which contain few inclusions of glass, biotite, and zircon in almost every case are plagioclase, though many of them are simple crystals, and twinning lamellæ are rare, one case giving angles which indicate labradorite. Though Lepsius makes the prevailing feldspar out to be sanidine, and hence calls the rock a "quartz trachyte," my own observations fail to confirm this. Though the crystals are generally simple and clear and hence look like sanidine, careful

search failed to diclose more than a very few which gave parallel or approximately parallel extinction. Moreover, the chemical composition of the rock is that of a typical dacite, and not at all that of a quartz-bearing trachyte or rhyolite.[1] The percentage of K_2O (1.66) is much too low for a rhyolite as rich in orthoclase as Lepsius makes out the rock to be. The percentage of CaO (2.98) again is much higher than that shown by any other rhyolite analysis, while quite in accordance with other dacite analyses. It is true that it is the lowest lime percentage of any of the rocks of the district, but this is quite in accordance with the comparative scarcity of feldspar, and its position in the albite-anorthite series. For these reasons the feldspar is held to be a plagioclase, and the rock is consequently a dacite.[2]

Tuff.—Only two specimens of this fragmental rock were collected. That from the west end of Mt. Chondos is light gray in color, rather finely granular, very friable, and shows evidence of stratification. Under the microscope it is seen to be composed of fragments of fresh olive-green hornblende, plagioclase crystals, magnetite grains, a few colorles augite crystals, and much microlitic groundmass with colorless glass base, patches and streaks of brown dusty material being very abundant, and there being no definite order in the arrangement of the above fragmentary constituents. No remains of organic beings, either animal or vegetable, were to be seen, and the specimen is evidently a tuff of the light gray hornblende-andesite deposited subaërially.

The brown compact tuff from farther east, near the top of the Chondos ridge, offers more points of interest. Megascopically it is very compact and fine grained, light brown and with a subgreasy luster. In this main mass are many rounded enclosures of a gray porphyritic hornblende-dacite, showing hornblende, plagioclase, and quartz phenocrysts, and resembling the dacite of Kakoperato.

Under the microscope the tuff shows a brecciated structure

[1] *Cf.* Analysis 15, in Part III.

[2] ZIRKEL (Op. cit. II. p. 258), on the authority of Lepsius, classes these rocks, as well as the hornblende-andesite of Poros, with the rhyolites.

composed largely of small angular fragments of the hornblende-augite-andesite of the Monastery district, with pieces of the brown hornblende, colorless augite, and plagioclase that occur in these rocks, this fragmentary material being cemented by a clear, colorless isotropic substance. Since chemical analysis (*cf.* No. 16, Part III.) shows that this tuff is very acid, containing 70.81 per cent. of silica, and since the rock of which the breccia fragments are composed contains only about 55 per cent. of silica, it seems certain that this glassy cementing substance is a form of amorphous silica, such a silicification of eruptive rocks being a not at all unusual phenomenon. This tuff is also, like the preceding, of subaërial origin. Through a misunderstanding no slide of the gray enclosures was made, but, as they present the megascopical characteristics of the Kakoperato dacite, they may be safely classed as analogous to these, though an analysis giving 71.49 per cent. of silica shows that they also have been subjected to the silicifying process.

The only other eruptive rocks found on Ægina were a block of a hard, greenish, aphanitic hornfels-looking rock which on examination proved to be a porphyry; a small rounded loose block of a coarse-grained biotite-granitite, with rather gabbro-like structure, and which probably came from one of the Cyclades as ballast; and many rounded fragments of white pumice found on the beaches of Ægina and Methana which undoubtedly have floated from Santorini, as they present the characters of this pumice, which I found on my visit there floating in large quantities in the inner bay of the island group.

Henry S. Washington.

(To be continued.)

LAKE BASINS CREATED BY WIND EROSION.[1]

In various parts of the Great Plains lakelets are somewhat abundant. At the north some of them occupy hollows in the uneven surface of the drift; elsewhere they are imprisoned by the unequal heaping of sand in dunes.

Those of a third class are independent of drift and dunes, and their explanation is not so readily apparent. They are so shallow that one may wade across them in any direction. They have no outlets and no permanent inlets. Their catchment basins are small. Ordinarily their basins interrupt divides between stream valleys, and they often rest on the highest tables of their vicinity. They are not permanent, but appear and disappear as storm and drought alternately prevail. Some basins are ordinarily dry, holding water only for a few days or weeks after a thunder storm. The lakes of others are approximately perpetual, disappearing only after a succession of dry seasons.

During the summers of 1893 and 1894 I rode extensively through a district in the Arkansas basin where these lakes are somewhat abundant; in one rectangular tract containing less than 1000 square miles twenty were noted. Various hypotheses as to their origin were considered, and at the end of the first season wind action was preferred, but less because its process was understood than because each other suggested hypothesis seemed barred by some insuperable obstacle. In the second season, however, some allied phenomena were observed which seemed to throw light on the subject and served to strengthen the hypothesis of wind action.

The rocks of the country include a sandstone and two limestones which constitute the crests of the uplands, but the greater part of the surface is occupied by shales. The shales sustain a scanty growth of grass, with here and there a shrub and, more

[1] Read to the Geological Society of America, December 27, 1894.

rarely, a few bush-like junipers. Their grade profiles are in general the typical products of subaërial degradation, convex upward on the divides and elsewhere gently concave. Interrupting these simple and familiar slopes there were found a few saucer-shaped cavities whose clean, smooth surfaces suggested at once their wind-swept character. They are almost wholly devoid of vegetation, and the shale from which they are carved is directly exposed without the intervention of residual or overplaced material. Three of them occupy a hillside sloping westward, so that the prevalent wind blows up hill. A part of the material excavated from these is deposited at their upper edges, and in the case of the individual most closely examined, has accumulated to such depth as to constitute a raised rim, deflecting the general drainage of the slope so that it passes around the hollow. The hollow itself is drained through several channels intersecting its lower edge. Rain and wind thus seem to be contesting for the mastery, and should the wind ever so deepen the saucer that it can contain without overflow the rain which falls upon it, a permanent lake basin may result. In another instance a small saucer is hollowed from an eastward slope, and here a clump of junipers standing at the lower edge has, by checking the wind, so aided the deposition of the detritus that the rim has been raised higher than the interior of the hollow and a temporary pool is the result. In yet another instance the hollow is carved on a southerly slope, and so deeply that it would pond the rainfall were it not tapped by a strong drainage line traversing the general slope at its eastern edge.

In each case the normal slopes of the country are sharply interrupted by the features of the saucer, whose steep sides descend quickly to a relatively level bottom. The wind seems to have first swept out a few feet of disintegrated and residuary material, and then been checked by the firmness of the unweathered shale in which it can work no faster than the rock is disintegrated by frost and kindred agencies.

In four of the five instances the rock attacked is a dark shale which is naturally almost sterile, so that vegetation on its surface

is exceptionally scanty unless it is coated by an overwash of other material. This relation suggests that the condition essential to the initiation of the excavation is the absence of vegetation. The function of vegetation as a defender of the soil against ravages of the wind is already familiar, and it is easy to understand that whenever a tract of land in an arid region is deprived by some accident of its vegetal covering, the wind may at once become an important factor in its sculpture, clearing away all disintegrated material and, if the tract is small, producing a hollow. If the hollow is so related to the slopes and drainage that it can gather water but will not be filled to overflowing, a permanent basin may result, for alternate flooding and drying will tend to keep the bottom of the hollow barren so that whenever it is dry the wind can continue its work. I believe the lake basins in question to have been created in this way.

In their present condition it is evident that they are naturally subjected to antagonistic processes dependent on the wind. While they contain water they receive dust from every gale that sweeps across the country, and the sediment thus accumulated, which is of no inconsiderable amount, tends, of course, to fill and thus obliterate them. When they are dry the wind resumes its erosive action and their bottoms are degraded. Professor Chamberlin has suggested an organic agency which also must constitute an important factor. In a region where springs and streams are rare the lakes are much resorted to by herds which, wading into the water to drink, carry away a coating of mud upon their feet and legs. The greater part of this mud is lost before they return, so that in this accidental way the beds of the lakes are steadily excavated and their margins enlarged. Horses and cattle sometimes increase their load by lying down in the mud, and their predecessor, the buffalo, is said to have the same habit.

With the pools called buffalo wallows I have little personal acquaintance, and I am not prepared to say whether their basins are initiated by the wind, or constitute an independent class with purely bovine origin. G. K. GILBERT.

ON CLINTON CONGLOMERATES AND WAVE MARKS IN OHIO AND KENTUCKY.

WITH A RÉSUMÉ OF OUR KNOWLEDGE OF SIMILAR OCCURRENCES IN OTHER SILURIAN STRATA OF THESE STATES, AND THEIR EVIDENCE UPON PROBABLE LAND CONDITIONS.

CONTENTS.

First record of the occurrence of pebbles in the Clinton of Ohio, by Professor Orton.—It is almost twenty-five years since the discovery of pebbles in the Clinton of Ohio was announced. The value of the discovery for determining the physical conditions which must have attended the deposition of this group was at once recognized. The Cincinnati anticlinal axis was believed to have been in existence as a land area in Paleozoic times, and the occurrence of pebbles towards the eastern border of the axis, the supposed shore line of Paleozoic times, seemed strong corroborative evidence of this view, and was believed to fix the

date of the initial rise of the axis, at least approximately. Curiously enough, in spite of the acknowledged importance of the discovery, Professor Edward Orton, the discoverer, and the now venerable state geologist of Ohio, seems to be the only geologist who ever visited the original pebble locality at Belfast, in Highland county, and so all references to the pebbles made by other writers are based upon his work. For that reason his original statement, made in the report of the Ohio Geological Survey for 1870, page 270, is here reprinted. Those parts of the quotation which recent discoveries seem to disprove are italicized:

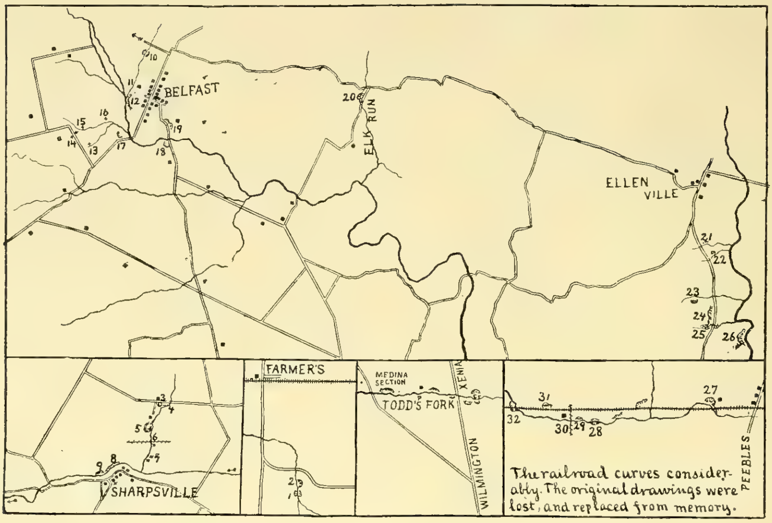
"A bed of limestone conglomerate, several feet in thickness, occurs near the *base* of the (Clinton) series in the southern part of the county. But a single exposure of the conglomerate has yet been noted. This is found one mile due west of Belfast, on the Belfast and Fairfax road, on the land of Charles Dalyrymple (localities 13, 14, and 15, of this paper).

"The pebbles that compose the conglomerate *appear to have been derived from the Blue limestone or Cincinnati rocks.* The conglomerate is also fossiliferous, well-worn forms of ancient life being incorporated with it. The fossils can be referred *either to the Cincinnati or* Clinton group, as they consist of forms that are common to both formations, viz., cyathophylloid corals of the genus Streptelasma and the remarkable fossil, Orthis lynx—a bivalve shell of immense vertical range, as is shown by its occurrence in the Trenton, Hudson (Cincinnati), Clinton, and Niagara limestones of the Lower and Upper Silurian ages, successively. It seems more probable, however, that the fossils in question were derived from Clinton seas rather than from the waste of rocks of a previous age.

"The occurrence of this conglomerate attests the existence of land near by—the shores of which were wasted by the sea, and the water-worn and rounded fragments of which were re-deposited on the floor of the sea. Since the first systematic study of the geology of the Mississippi Valley, proofs have been accumulating that a Silurian island stretched northeastward from Nashville, towards and beyond Cincinnati. Highland county furnishes its full quota of facts as to the existence, and as to certain of the boundaries of this ancient land. Other facts will be adduced that bear upon this point in the description of the remaining formations of the county. The date of the uplift of this island is approximately determined by the fact already quoted—as land at the westward is found in existence *early in the history of the Clinton.* This folding of the crust, then, that transformed a portion of the ancient sea bottom into dry land, probably occurred about the close of the Lower Silurian

time, and it seems also safe to say that it not only marks the date but *furnishes the producing cause of the change in the formation that then took place.* The Medina shales may be referred to sediments that settled in seas, disturbed by igneous agencies—the long continued life of the preceding periods being exterminated in this region by the shallowing waters, as the low mountain chain emerges."

The change in formation, to which reference is made above, is that from the alternating limestones and clays of the Cincin-



Sketch maps of localities referred to in this article.

nati group to the shales of the Medina. Volcanic disturbances sufficient to keep the sediment of the sea in commotion, are hardly necessary to account for the change in the lithological character of the two formations.

Former observations by the writer, based upon Professor Orton's material.—Some years ago Professor Orton kindly placed at the disposal of the writer the pieces of conglomerate which had come from the original locality near Belfast. At that time it was noticed that the fossils contained in the cement among the pebbles were all of Clinton age, and not a single species of Cincinnati group affinities was found. Even in the case of Orthis lynx it was the Clinton form, and not one of the Cin-

cinnati group forms, which had been found. The pebbles of the conglomerate fragments collected by Professor Orton, were unfossiliferous, though fossils have been found recently, as described below. The lithological appearance of the pebbles was unlike that of any of the limestones known from the upper part of the Cincinnati group in Ohio.

It seemed therefore that some of the statements made in the original publication needed re-investigation, before they could be considered a safe basis for conclusions as to the probable physical and geographical conditions which obtained in Clinton times. A week was therefore spent in Clinton, Highland, and Adams counties, and sufficient material was found to disprove some of the original statements and to shed quite an additional amount of light upon the problems involved.

The original material is given in the following pages in full. Abstracts of pertinent observations made by other writers are also presented. Those who are more interested in the conclusions at which we have arrived, than in the facts upon which the conclusions are based, will find the former concisely presented at the end of this article.

PEBBLES AND WAVE MARKS IN THE CINCINNATI GROUP.

Observations of the Kentucky Survey.—In order to understand the physical conditions which prevailed during the Clinton epoch in Ohio, it is necessary to study this problem in connection with conditions existing both before and after this epoch. Since the central counties of Kentucky are also involved in the Cincinnati anticlinal axis, any facts which they afford will also be of interest. The following facts are collated from the more recently published reports on the geology of the various counties. With the exception of the report on Marion county, by W. T. Knott, and that on Clinton county, by R. H. Loughridge, these reports are all from the pen of W. M. Linney.

Trenton.—In Garrard county some of the layers are very irregular in their bedding, and some show wave marks. In Clark county the irregular stratification sometimes amounts to

cross-stratification, and at one locality great wave marks are found. Near the top of the Trenton are often seen rounded pebbles of limestone distributed in thin beds for a number of miles. They are mentioned from Garrard, and also from Clark and Montgomery counties.

Lower Hudson.—These beds are considered by Mr. E. O. Ulrich as being in large part equivalent to the Utica. Mention of wave marks is made from the following counties: Shelby, Spencer, Washington, Marion, Mercer, Garrard, Madison, Clark, Montgomery, Bath, Fleming, and Mason. The wave marks occur in the upper beds of this division. In Mercer county they are stated to occur 140 to 170 feet above the base. Their occurrence in the *upper* beds is more or less directly inferred from statements made with reference to these layers in Spencer, Washington, Mercer, Garrard, Madison, Bath, and Mason counties, and this is presumably their horizon also in the other counties. Cross-stratification occurs in the upper beds in Mason county.

Rounded limestone pebbles are stated to occur only in the case of one county, Washington. Here the lowest layer of the Lower Hudson is said to be about one foot in thickness, and to contain usually some rounded limestone pebbles. The occurrence of pebbles in Clark and Montgomery counties seems to be warranted by the following statement made, under the title of "Disturbances in Clark and Montgomery," in one of the reports: "In the Lower Hudson beds, where the alternations of hard limestones and shales are so constant, the intervals were produced by corresponding changes of condition, and in these hard layers are sometimes seen large pebbles of limestone, which have been worn until half round and then consolidated with finer material." In this case no particular horizon is mentioned.

Middle Hudson.—Wave marks are mentioned from Nelson, Washington, and Mason counties. In Washington county they are said to occur at the base. Those from Mason county are not located, and the reference to them is suspicious, as though the wave marks belonged to the well-known waved beds of the

Lower or possibly even the Upper Hudson, rather than the Middle division, under which the reference happens to occur.

Upper Hudson.—Cross-stratification occurs in the lower beds in Clark county; it is said sometimes to resemble large wave marks. The same conditions seem to occur also in Montgomery county. Wave marks occur in Oldham, Lincoln, and Fleming counties. Their position in Oldham seems to be somewhere beneath the top; in Lincoln they are found at many horizons; in Fleming they are located near the top of the series. In Spencer county indurated clay balls are found in the earthy limestones and shales near the top of the Upper Hudson. Under "Disturbances in Clark and Montgomery Counties" rounded pebbles of limestone are said to occur in some of the strata of the Upper Hudson.

Observations by E. O. Ulrich.[1]—At the base of the Lower Hudson there is generally a layer of limestone, one foot or so in thickness, which usually contains some rounded limestone pebbles. No localities are given, but Mercer, Boyle, and Washington counties are mentioned in the preceding sentence, and the occurrence of these features here and in other counties of central Kentucky may be inferred. See, for instance, the reference to a similar layer at the same horizon in Washington county, given above from the Kentucky Survey. In West Covington opposite Cincinnati, and about a mile west of the mouth of the Licking, the conglomerate occurs, which is to be more fully described, just below, from personal observations made in company with Mr. Ulrich. This locality belongs to the Lower Hudson, or the Utica of Ulrich. It is described by Professor N. S. Shaler in one of the earlier reports of the Kentucky Geological Survey. The waved-layers, which occur at several localities near Cincinnati, are correlated with the wave-marked layers so frequent near the top of the Lower Hudson in the other counties of Kentucky (Am. Geol., 1888, page 314).

In Washington, Boyle, Lincoln, Garrard, Madison, and Clark counties, the strata belonging to the top of the Middle Hudson and the bottom of the Upper Hudson are decidedly arenaceous,

[1] American Geologist, 1888, May, pages 308–310.

this feature being much more pronounced and of greater extent in southern Kentucky than in Ohio and Indiana. In fact, some of the lower portions of this series may with truth be called sandstones.

Observations of Dr. John Locke at West Union; Upper Hudson.—The locality is twelve miles a little east of south of Elk Horn creek, near a house known as Treber's at the time of Locke's report (Geol. Surv. Ohio, 1838, p. 246, and plate 6), in the bed of Lick Run. It is about four miles northeast of West Union, as nearly as can be determined from the report. Here, about fifty-five feet below the level of the Clinton, for a distance of 400 feet, wave marks occur in the upper Cincinnati group beds, with crests two to three feet apart, and two to three inches above the troughs. According to Locke they may be traced at about the same horizon for miles.

Observations of Professor Orton.—In Vol. I. of the Ohio Survey report, page 377, Prof. Orton mentions that Locke noted the wave-marked layers in the upper beds of the Cincinnati group, and then states that they are even more characteristic of the lower beds (the Lower Hudson of Kentucky reports) as shown in the river quarries of Cincinnati, or in the 100 feet that are there exposed. These wave-marked layers are said in every case to be overlain by shales.

OBSERVATIONS BY THE WRITER.

West Covington, Kentucky (Lower Hudson, or Utica of Ulrich).—Opposite Cincinnati, halfway between the Chesapeake and Ohio and the Cincinnati Southern railway bridges, opposite house No. 31, along the road skirting the river front, nearly at the top of the section exposed along the Ohio river is a well stratified, sandy-looking limestone layer, in places almost two feet thick, which can readily be traced for a considerable distance along the river front. Over this lies a layer composed chiefly of coarse crinoidal remains but containing also many bryozoan fragments, and some brachiopods. The crinoidal layer is about twenty inches thick. Its chief interest consists in the fact that

it evidently lies upon an eroded base, the underlying sandy-looking limestone having suffered more or less marked erosion previous to the deposition of the crinoidal layer. Owing to the marked stratification of the sandy limestone, the irregular erosion of its upper surface is readily observed, and the crinoidal layer is seen in places to descend considerably below the original level of the sandy layer. In some places the sandy limestone has been cut through so that the crinoidal bed rests upon the bed below the sandy limestone, but in the stretch examined along the river front the erosion seems to have been confined chiefly to the sandy layer and rarely extends to the layer beneath. Nothing could better express the limited vertical range of this erosion. In the crinoidal bed occur many fragments evidently derived from the sandy layer immediately beneath. Some of these fragments are of considerable width, slabs as long as two and a half feet having been seen inclosed in the crinoidal layer. The thickness of these fragments rarely exceeds four inches and is usually less. One slab of sandy limestone must have been at least five feet long, but this was exceptional. The usual length varies from four to seven, at times twelve inches, and the thickness varies from one to two inches. The edges are usually more or less rounded, but not to the same extent as are the pebbles of some of the Clinton conglomerates. Many of these pebbles occur near the base of the crinoidal layer; fewer are found in the central parts of this layer, but quite a number occur again, in places, at the top. It is very evident in this case, that the pebbles could not have been derived from a distant source, but must have been carried to pockets and depressions already formed in the sandy layer, while other parts of the same layer, at some point in the more immediate vicinity, were suffering erosion. Occasionally inclusions are found which were not derived from the sandy layer beneath. In one case, at least, a fragment of a coarsely crinoidal rock was included in the crinoidal layer; it was very similar to the inclosing rock, but its lines of stratification had a different angle. Rounded chunks of a clayey substance at present hardened, very fine-grained, and yellowish in color,

also occur; in places, plentifully; almost always near the top of the crinoidal layer, rarely towards the middle, and never at the bottom. They evidently were derived from a slightly greater distance than the sandy pebbles, but similar clayey rocks occur abundantly just above the crinoidal layer in the present section, and it does not seem necessary to imagine derivation from any considerable distance, since rocks having this lithological character may have occurred at a lower horizon not far off. The top of the crinoidal layer occasionally shows a heaping up into ridges or wave marks. Wave marks are, however, more frequently and better shown in the layers just below the sandy bed. More frequently these wave marks are associated with irregular ripple marks making it impossible to determine the direction of the markings. In a general way they may be said to run slightly east of north, but the wave marks are hardly sufficiently well oriented or distinct to make it worth while to draw conclusions from the same. The crinoidal layer frequently shows bedding, and in that case, the stratification lines usually incline strongly to the west, giving rise to a sort of cross bedding, when seen in conjunction with the stratification planes above and below. After having studied this layer, it is easy to understand how the pebbles in the Cincinnati group at Elk Horn, east of Winchester, and in the various Clinton conglomerates, could readily have been derived from the layers immediately beneath.

Winchester (*Upper Hudson*).—Elk Horn creek is crossed by the Cincinnati, Portsmouth & Virginia railroad about a mile and a quarter east of Winchester. This region is about 10 miles west of Peebles, and 10 miles southwest of Belfast; it is 39 miles a little east of south from the Todd's Fork locality. The trestle crossing the creek is about 75 feet high. Down the creek from the bridge is a magnificent exposure of wave-marked Cincinnati rock. The highest hills around Winchester, and also in the direction of Elk Horn and Brush creeks, show Cincinnati rocks, so that this exposure must lie at least 60 feet beneath the level of the Clinton. The wave marks are exposed for several hundred feet along the bed of the creek below the bridge. The crests

run north and south, are often three inches above the troughs, and are usually about 30 inches apart. Plenty of fossils occur just beneath the sand forming the wave ridges themselves, and they protrude through the same. On going down the stream lower horizons are met, and wave marks are also found at these lower levels. Farther down stream the wave marks run north 50° west and are not so fine as those first described. Still farther down stream are plenty of good pebbles caught up in the layers beneath the wave marks. The pebbles are often six, and occasionally eight and ten inches in diameter. They evidently were derived from the sandy, stratified, less fossiliferous beds of practically the same age which occur immediately beneath. While there was not found the same direct evidence of the derivation of these pebbles from other localities in the immediate vicinity, as opposite Cincinnati, this was probably due chiefly to less favorable exposure, those at Elk Run occurring chiefly in the creek bed, and those at West Covington being exposed on the steep banks of the Ohio in almost vertical section. While the pebbles were, as a rule, not richly fossiliferous, yet owing to their great abundance their identity could be readily established. All fossils found belonged to the horizon of the general matrix in which they were inclosed, showing their derivation from rocks of but slightly lower horizon.

Below the first house on the west side of the creek very good wave marks are again seen running north and south for a considerable distance. Farther down are others less good but distinct, running north 30° west. Within half a mile of the bridge, farther down, opposite a house on the east bank, plenty of pebbles occur in the rock. Some of these pebbles are slabs 16 inches in diameter, and about an inch to an inch and a-half thick. Just below, the wave marks run north 20° west. At a very considerable distance down the creek are loose slabs containing pebbles of moderate size, two to three inches in diameter. Farther down are poor wave marks, the usual distance apart and running north 45° east. Just below these are good wave marks running north 20° east. Some distance beyond this, Elk Horn

creek enters into Brush creek. It will be noticed that the good wave marks were those running north and south or more nearly in this direction; those running more northeasterly or northwesterly were poor. This probably means that the strongest brunt of the waves and freest exposure to the sea lay directly westward at this point. Going up Brush creek, at a locality not far distant from the junction of the Elk Horn creek a layer showing wave marks was found. These were not recorded, but are believed from memory to have run north 30° west.

Observations by Nelson W. Perry and Joseph F. James.—Wave marks and raindrop impressions occur at Smiley's dam on Four-Mile creek, near Oxford, Ohio, at a level 600 feet above the Mt. Pleasant beds. On the Little Four-Mile creek, at Ridenour's Mills, wave marks occur, going up stream. Mud-cracks are found in Dearborn county, Indiana, 600 feet above the Mt. Pleasant beds. These occurrences probably belong therefore to the Upper Hudson of Kentucky geologists.

AUG. F. FOERSTE.

(To be continued.)

GLACIAL STUDIES IN GREENLAND. III.

Coast Glaciers between Disco Island and Inglefield Gulf.

From the southern extremity of Greenland to the vicinity of Upernivik the ice-cap lies so far inland as to be but rarely and imperfectly seen from a coasting vessel. Here and there it forms the sky line between the mountains, and at intervals tongues push down the valleys to the inner coast line, but only such fragmentary views are offered to the passer-by. Even for a degree and a half beyond Upernivik, little may be seen of the interior ice-field, though nothing but a coastal fringe of islands intervenes. The Devil's Thumb, that grewsome landmark of the navigator, which stands over against the dreaded ice pack of Melville Bay, must be passed before the border of the great ice-field comes fairly into view.

It may be recalled that from Cape Farewell to the Devil's Thumb the coast has a mountainous aspect interrupted at intervals by lower tracts of fluent contours. Its general expression is harsh and rugged. Patches of snow and local glaciers give it an Arctic aspect; still it is more nearly ice-free land than an ice-field. It is a black-and-white border to the great white interior. Near Upernivik this border becomes reduced to a fringe of mountainous islands. These disappear near Lat. 74° 30′, and the great ice cap comes out to the coast and by its precipitous ice-walls forms the sea border. The Devil's Thumb, situated on one of the most northern of these bordering islands, becomes the sentinel of the transition from the one type of coast to the other. It is a columnar monument of rectangular aspect surmounted by a more slender column, not altogether unlike the combination of the Auditorium tower, if a local comparison may be permitted. A resemblance to his majesty's opposable digit would never have occurred to me, but this may be due to a lack of personal

acquaintance. There was certainly also a lack of suggestive associations; for as a relatively slender column standing only a few miles from the edge of the great ice sheet it awakens in the glacialist thoughts lying in quite opposite thermal relations. What does this column so situated signify respecting the former extension of the ice? There are better reasons than the temperature associations of his majesty for thinking that the ice may never have passed over the Thumb since its isolation. Without fuller knowledge, however, there is an open alternative between the view that exfoliation has developed the monument out of a peak or promontory since the ice passed over it and the view that the ice never advanced so far. Melville Monument, a somewhat similar rocky column rising out of the bay off the face of the ice border a degree farther north, presents a similar alternative, as do also some of the rather rugged islands along the coast, though the majority of these are fluent in contour, and carry implications of precisely the opposite kind.

Beginning just beyond the Devil's Thumb, at about latitude 74° 30′, the coast of Melville Bay, for about 150 miles, is formed much more largely of ice than of land. A survey has recently been made by Mr. Astrup, of Lieutenant Peary's party, which will, when published, add greatly to the existing knowledge of this remarkable coast, which is laid down on our charts with confessed inaccuracy. Not to anticipate this, it may be safely affirmed, on the basis of passing observation, under the favorable conditions of our voyage, that while the coast is not the uninterrupted ice-wall that sailors sometimes represent it (due, perhaps, to the deceptiveness of its frequent and phenomenal mirages) its most dominant and interesting feature is the edge of the great ice-field broken into vertical sea cliffs as it pushes out into the margin of the bay. These cliffs, though very extended, are not wholly continuous. They are occasionally interrupted, not only by promontories standing forth from the base of the ice slope like dormer windows at the eaves of a roof, but also by lower areas whose freedom from ice is less obviously due to altitude. These interruptions, however, are usually limited in

extent. The promontories are closely girt about by ice on their sides and in the rear, and lack only enclosure on the sea face to reduce them to typical nunataks. Indeed, many of the prominences that lie a little back from the coast are thus completely surrounded, and present excellent types of islands in the ice, the Greenlander's nunataks.

From a vessel sailing some distance off the shore (and the broad foot of stationary bay ice rarely gives a ship any other privilege), a considerable tract of the upper slope of the glacier is visible. The sky line lies some miles inland. Only a few of the promontories on the coast rise high enough to be projected across this sky line and interrupt the otherwise continuous stretch of the glacial horizon. The ice does not meet the sky in a simple straight line. It undulates gently, indicating some notable departure of the upper surface of the ice tract from a plane. As the ice-field slopes down from the interior to the border of the bay, it takes on a still more pronounced undulatory surface. It is not unlike some of our gracefully rolling prairies as they descend from uplands to valleys, when near their middle-life development. The convexities are much broken by crevasses. It is not a few gaping fissures here and there, or even at regular intervals, but an intimate cracking open of the whole convex surface, so as to alter its entire expression. As a result, the light reflected from the crevassed portions is brighter than that from the smoother parts, and the undulations are thus set forth delicately but very expressively by the varying tones of the nearly white light. The intimacy and extent of the crevassing on the swelling surfaces is quite remarkable when the relative slightness of their convexities, the breadth and freedom of the sheet, and the evident slowness of motion are considered. The slowness of motion is safely inferred from the limited amount of surface wastage during the short season, and the very moderate iceberg product in proportion to the vast frontage. The undulations are undoubtedly due to the inequalities of the rock surface below. The first impression is that the ice sheet is quite thin and altogether subservient to the basal irregularities. And this is doubt-

less measurably true. But it appears also to be an expression of brittleness rather than of viscidity, as a property of the ice. Its competency to stretch must be very slight. The degree of undulation also shows a feebleness of adaptive fluency.

The surface of the ice seemed to be wholly free from rocky débris save where contact with promontories or nunataks give rise to trivial moraines. Except for these the bay ice seemed no more free of débris than the surface of the glacier. The descent from the sky line to the sea wall must be some 3000 feet, and yet it would appear that no material is brought from the base to the summit. The exposed portions of the icebergs of the region are usually quite free from débris. In a few instances interbedded earthy layers were observed.

A considerable number of icebergs were scattered along the front of the sea wall, held fast within the sheet of bay ice that still remained stationary. In the moving portion of the ice pack comparatively few were seen. It is obvious that the icebergs enclosed within the stationary ice embraced all those that had been discharged since its freezing, which was at most not more recent than the previous fall; indeed, they probably embraced not a few that had been discharged much previous to that, for many of them appeared to be aground, and to have been subjected to considerable wastage since they had been discharged. Large numbers of icebergs were aground on the shallows near Cape York and along the face of the Crimson Cliffs. Captain Nares expresses the opinion that these bergs originated in Melville Bay and were carried westward by the tide, which, coming from the south, is turned to the west by the concave contour of the bay. If this be true, perhaps it should increase somewhat our estimate of the discharge from the Melville ice wall, but the fact that they are aground and wasted, extends the time through which their discharge is to be distributed.

Peaked Hill, a conspicuous landmark on the north side of Melville Bay, introduces another transition of the coast phenomena, a reaction in some measure toward the conditions that prevail south of the Thumb. Peaked Hill is a cone set upon an

irregular ridge, with black, rather ragged outliers in the vicinity. The whole combination has a very volcanic aspect, but there is little or nothing in this upon which to base an inference respecting its nature. Westward from Peaked Hill there are frequent protrusions of hill and mountain crests and ragged outliers, arranged in an irregular scattered way, but sufficiently thick to give the sea frontage quite as much the expression of a range of mountains with attendant glaciation, as of predominant glaciation interrupted by mountainous projections. The inland ice may be seen sufficiently through the gaps to show that it dominates the country immediately in the rear, and that the mountainous aspect is purely frontal. Frequent ice tongues come winding down between the hills to the sea, and to some extent glacial sheets wrap them about, while local glaciers and snow blankets cover portions of their slopes. The total expression is much more glacial than that of the land border south of the Melville ice wall.

Into the bay east of Cape York very considerable glacial tongues descend from the east, north and west. They push well out into the bay, which probably signifies that it is shallow. During the past season the ice did not move out of the bay (at least it had not at the time of our return, when the season of new ice was at hand) and hence all the icebergs recently discharged remained embedded in the stationary ice. Mr. Astrup informs me that the ice does not usually move out annually but remains for a period of years, and, partly by deeper freezing and partly by snow accumulations, acquires considerable thickness. When it is finally forced out it forms at least a variety, if not the typical variety, of "palæocrystic" floes. Mr. Astrup thinks that glaciers sometimes force such floes out.

Cape York is a promontory of ancient crystalline rock, standing at the junction of Melville Bay with the northern extremity of Baffin's Bay, where it narrows rapidly into Smith's Sound. From this point west-northwestward for some forty miles, the Crimson Cliffs present an abrupt plateau face, down the ravines of which creep a dozen small glaciers. The name "Crimson Cliffs"

is variously attributed to the reddish lichens that grow upon the face of the rocks, and to the "red snow" (*Protococcus nivalis*) which in the latter part of the season gives a very notable pinkish tinge to the remnant snow banks and the granular surfaces of the glaciers. The glaciers take their origin in an undulatory nevé surmounting the cliffs. This appears to be continuous with the great snow cap of the interior, but from its apparent thinness and strong undulation in evident conformity to the rock surface, it seems probable that it is, in effect, a local ice cap. It is probable that the Cape York glaciers on the one hand and the noble

FIG. 15.—Distant view of the Crimson Cliffs, showing ice cap, glaciers, icebergs and ice floes.

Petowick glacier on the other, draw away and discharge the surplusage of the adjacent portion of the main ice cap, so that it does not push forward over the edge of the Crimson Cliffs. At any rate, the glaciers that creep down the face of the Crimson Cliffs are all small and give no hint of relationship to anything beyond the limited though rather considerable snow fields on the summits immediately above them. These little glaciers descend steeply, winding through their narrow valleys in full conformity to topographic demands. The most of them do not fully reach the sea level, but terminate at varying heights above it. A few actually protrude into the water, and have vertical frontal cliffs. Terminal and occasional medial moraines are present. There appears here an interesting phenomenon which was frequently

noted farther northward—the construction of a causeway by the glacier through the accumulation of its own débris beneath it. In their upper parts the glaciers appear to fit snugly in their respective valleys, and they doubtless have carried along with themselves all débris that may have been loosened beneath them; but on reaching the lower gradients near the sea level much of this has been deposited, so that they are now creeping out on embankments of their own construction. It is perhaps not necessary to

FIG. 16.—Distant view of a part of Petowik glacier. Ice mass in foreground showing cavernous melting at former water-line with subsequent tilting.

suppose that they have built these up actually beneath themselves, as they may have constructed them by successive terminal deposits. When shorter than they now are they may have thrown down their material at their front edges, and subsequently have advanced upon it, building out the terminal accumulation in front as they slowly advanced. Whatever be the explanation (and passing observation gave no data for determining the mode of construction), the interesting fact remains that the glaciers become subservient to their own accumulations, instead of forcing them bodily out of their way.

Near the western extremity of the Crimson Cliffs there stands,

two or three miles off shore, a very notable island, known as Conical Rock. Its name indicates its form, but does not suggest the jaggedness of its surface, which is quite pronounced, and again raises the question whether the great ice sheet has ever passed much beyond its present limits.

A short distance beyond this, the Petowik glacier, the noblest of the isolated glaciers of this portion of the coast, presents itself. It has a breadth of seven miles, and arches forth gently into the bay. Its profile is singularly regular and rises gently as it stretches back from the edge of the sea cliff into the interior, where the glacier merges into the plains of the inland ice. Its transverse profile is a gentle arch with but slight convexity in the central part. The upper surface is comparatively free from crevasses, and nowhere in its course, so far as seen, did it show any cataracts. Its general expression is similar to that of the great Frederickshaab glacier of South Greenland, though it is much inferior to it in dimensions and impressiveness. The Petowik glacier appears to be relatively inert, discharging but few icebergs.

Between the Petowik glacier and Wolstenholme Sound, the coast is relatively free from snow and ice. In the depths of the Sound large glaciers descend to the sea level or to its vicinity, but only very distant and imperfect views of these were had. Dalrymple Island, in the mouth of the Sound, closely resembles Conical Rock in its form and surface ruggedness, and doubtless has the same significance. A photographic illustration of it has been given in the introductory narrative (Fig. 3). Saunders Island, which stands farther within the mouth of the Sound, introduces us again to stratified clastic rocks. These have been absent since we left the Disco region. From this point they stretch to Cape Alexander, at least, though they are not everywhere the border rock. So far as identified, they consist of sandstones and shales.

Along the shores of Granville Bay, and northward to Cape Parry, at the mouth of Inglefield Gulf, there are several glaciers of medium dimensions which descend from the ice cap of the plateau immediately above them, which is an extension of the

inland ice. These glaciers, however, occupy only a small fraction of the coast, the greater portion of which is ice-free land. It differs from that of South Greenland in the important fact that it is a plateau border and not mountainous. The clastic rocks are rounded into soft contours, whether by long exposure to meteoric agencies or to glacial action is not evident at a distance, and need not be considered here, as this brings us to the entrance to Inglefield Gulf, where a closer examination will be possible.

This running sketch of passing observations has brought into imperfect view the various coastal types of West Greenland; rugged serrate mountains; rounded sub-mountainous tracts; coast-island fringes; ice-fields ending in sea cliffs; ice-fields struggling with mountainous protrusions; rock-walls capped with nevé and traversed by "hanging" glaciers; and plateaus of softened outline, surmounted by ice-fields whose tongues creep down wide and less steep valleys.

T. C. CHAMBERLIN.

Studies for Students.

AGENCIES WHICH TRANSPORT MATERIALS ON THE EARTH'S SURFACE.[1]

Contents.

When account is taken of all the foregoing considerations touching the character of the drift, the character of the rock surface which underlies it, and the relation of these to each other, we are able to exclude as principal agents of the drift, many of those forces which transport materials on the earth's surface. The agencies prominently concerned in shifting loose materials are wind, water and ice. Other agencies of extreme violence, such as earthquakings and volcanic explosions, occasionally affect small areas. Suddenly and locally they accomplish very considerable results in the way of shifting material from one point to another. The direct action of gravity, too, by producing landslides and by carrying loosened masses of rock down steep slopes effects much in the way of transfer of surface materials. But we have no warrant for believing that any or all these agencies can move such materials as those of the drift

[1] The sequel to the articles which appeared under the heading *Studies for Students*, Vol. II. Nos. 7 and 8.

through any such distances as the drift has been carried. On the contrary, we have the best of reasons for believing that they could not.

Wind.

The strongest winds are able to carry no more than very small pebbles along with the sand and dust which make up their chief load. Transportation of the drift by the wind is therefore impossible. Locally the wind has moved the sand of the drift, heaping it into dunes or spreading it with more uniformity over surfaces which it did originally occupy. But although the wind may have played a part in the deposition of the great body of material included under the term drift, either at the time of its origin or since, it can have been no more than a very subordinate factor. The work of the wind, so far as the great body of drift is concerned, can be looked upon as nothing more than incidental. There remain to be seriously considered, therefore, only two agencies, ice and water.

Water.

Next to the wind, moving water is by far the most widely active agent which is now shifting material on the earth's surface. The countless streams, large and small, the waves and currents of the thousands of lakes, as well as those of the seas, are constantly moving those materials which come within their reach, and do not exceed their power. Streams, waves and currents, do each their appropriate work. The results have much in common, yet each has its diagnostic marks.

Streams. Streams sometimes carry heavy burdens of earthy material. If the velocity of a stream be great, and particularly if its gradient be high, it is able to roll along stones of considerable size. The torrents which course down hillsides after violent showers sometimes carry blocks of stone weighing hundreds of pounds. If the high velocity of the transporting stream were to be constantly maintained, great quantities of coarse material might thus be carried down in the long process of time. The presence of coarse material, even bowlders of some size, is

therefore no proof that the deposit containing them was not made by a stream.

The transportation of coarse materials by streams may be facilitated by the co-operation of ice. When the rigors of winter are past, and the snows upon the hills and mountains are being rapidly melted, the swollen streams break up the ice which has imprisoned them, and hurry the broken masses forward with their increasing floods. As these masses of ice are torn away from the banks of the streams, they sometimes carry with them very considerable quantities of earth, sand, gravel and even bowlders, to which the ice had frozen. These materials are deposited at some point further down the stream, or in the lake or sea to which the river flows.

But however we may conceive the work of rivers to be abetted, the material which they transport could never be deposited on land surfaces outside the limits of their valleys. It might be distributed widely by the waves and currents of the seas and lakes into which the rivers carried it, but it could never be deposited on the tops of hills or mountains. Furthermore, the deposits made by streams, except in the case of alluvial cones, have surfaces which are nearly plane. They are never marked by such hills and depressions as often characterize the drift. The difference is not one of degree, but one of kind. However vigorously we may suppose streams to have acted, therefore, and however we may suppose their proper work to have been modified by co-operating agencies, they fail to account for the distribution of the drift or for its topography; and not only do they fail to account for the distribution and topography of the drift, but its distribution and topography are such as to constitute positive and conclusive evidence against the reference of the larger part of the drift to rivers acting under any circumstances whatever. Since the distribution of the drift disproves all hypotheses which ascribe it to rivers, the argument need not be pursued further. But if we were to examine in detail each of the characteristics of the drift with reference to its production by streams, we should find that their combined testimony is

not only negatively but positively overwhelming against the notion that the bulk of the drift can be accounted for by any phase of river work of any degree of intensity assisted by any other agent in a subordinate capacity. Streams, then, were not the principal agencies concerned in the deposition of the drift, though nothing here said is to be construed to mean that they did not play a subordinate part. The fact that stratified drift frequently extends much further south in valleys than on the adjacent uplands suggests that rivers may have played a subordinate rôle in the transportation and deposition of the drift.

Materials deposited by streams along their valleys are properly called "river drift." Generally speaking, river drift is so unlike the general sheet of drift under consideration, both in its inherent character and in its relations, that the one is not likely to be mistaken for the other. Yet the range of variation, both in the drift and in river drift, is great. When the variations are toward a common limit, as is sometimes the case, the one may closely simulate the other. But this does not appear to be true of any considerable body of the two types of drift, extending over any considerable area. Torrential deposits, such as are formed at the bases of steep mountain slopes, or along the valleys of streams which have high gradients, may closely resemble the drift so far as their physical constitution is concerned. But the distribution of such deposits, the shapes of their constituent stones, and their freedom from striation and planation, are generally sufficient to betray their origin. Lithologically, too, torrential deposits contain only materials which might have been gathered from the drainage basin of the stream concerned, while the constituents of the drift are rarely so limited in their range. If the materials entering into the constitution of torrential deposits were derived from the drift, and not greatly modified in the process of reworking, the resemblance of these deposits to the drift, and especially to the stratified drift, might be very close. Even in this case their distribution and structure might be decisive. Furthermore, if the existence of the drift must be presupposed in order to account for torrential deposits

which might be mistaken for the drift, it is clear that we have in the torrents no explanation of the drift itself.

Lakes and seas. By their waves and currents lakes and seas effect extensive transportation. Along the bases of steep cliffs storm waves sometimes have sufficient strength to move loose masses of rock many tons in weight. But bowlders so large as those common to the drift cannot be moved by the water of lakes or seas except along shores where waves are violent. Even along shores subject to strong waves, great bowlders cannot suffer extensive transportation at the hands of waves and currents. Even where the movements of the water are competent to transport them, they are worn out, or at any rate greatly reduced in size, before being carried far. Yet some of the huge bowlders of the drift have journeyed scores and even hundreds of miles, and that over regions where there is not only an absence of evidence that shores existed, but where, on the contrary, there is the best of evidence that shores did not exist during the time of drift formation, and where there is the best of evidence that seas or lakes have not existed since that time. Neither sea nor lakes can be responsible for their present position.

Again, deposits made by seas and lakes are composed of materials which are well assorted and stratified. The larger part of the drift is neither assorted nor stratified. Deposits made by seas and lakes contain relics of the plant and animal life which inhabited them while the deposits were making. The great body of the drift is devoid of lacustrine and marine fossils. In certain restricted localities, however, the drift contains marine fossils and in certain other restricted localities lacustrine fossils. The significance of these exceptions will be noted later. In spite of them the statement remains true that marine and lacustrine fossils are generally absent from the great body of the drift. It is hardly necessary to state that where the drift is made up in part of rock which contains fossils, these fossils reappear in the drift. Such fossils have no significance except in showing what formations contributed to the drift of the localities where the fossils exist.

Deposits made by standing water are necessarily restricted in

their vertical range. They cannot extend above the level reached by the crests of the highest waves, and in great thickness they cannot extend below the depths reached effectively by the bottoms of the waves. Although small amounts of fine sediment may be carried far out into lakes or into the sea, especially along the courses of currents, yet considerable deposits of lacustrine or marine sediments coarser than fine clay must be confined to a narrow belt of shallow water along the shores. Even within this belt there is a systematic gradation of material on the basis of size, the coarser being left nearer the shore, while only the finer reaches the outer part of the zone of abundant deposition.

If the level of the standing water along whose shores deposits are made varies, the shore deposits made at successive stages will have a corresponding vertical range. The deposits making at any given time must have an essentially horizontal upper limit, corresponding approximately with the level of the water. The earth's surface parts are known to be undergoing differential vertical movements, and are known to have suffered such movements in the past. It follows that shore deposits, horizontal in position at the time they were made, may not always remain so. But if they fail to preserve their original horizontal position, they can never assume any new position except such as might be given them by crustal movements.

No lake and no combination of lakes could cover the area which the drift covers. The only body of water which could have been everywhere where the drift is, is the sea. If the sea covered the whole of this area, including its mountains, and if the land gradually rose, or the sea receded, all parts of the drift area would have found themselves, sooner or later, at the level of the sea. In this way only could all parts of the drift-covered area have been affected by those parts of the sea along which, and along which only, abundant deposition of coarse materials can take place, if water alone be concerned.

To account for the absence of drift from the southeastern part of the United States, lower on the whole than the drift-covered territory to the north, it would be necessary to suppose that this

area was high at the same time that the drift area was submerged, if the sea was concerned as a principal agent in the origin of the drift. Such a supposition, if made, would have to be made not only without supporting evidence, but in the face of abundant and positive adverse evidence. If anything further need be said in refutation of the violent hypothesis referred to above, reference might be made to the position and relations of the line which marks the southern terminus of the drift. It will be remembered that this line is far from horizontal. Not only this, but it is a line which could not have been deformed from a horizontal position by post-drift warping. Without inquiring whence the sea could have derived material for such coarse deposits as the drift, in case the whole of the drift-covered territory was submerged, such extensive transportation of coarse material as the drift demonstrates could not have taken place at the hands of water alone.

Thus from the cursory examination of a few of its characteristics it is seen not only that lakes and seas, unaided by other agencies, fail to account for the drift, but that the drift bears in itself and in its relations, positive and conclusive testimony against the suggestion of its genesis at the hands of lakes or sea, acting as principal agents. The nature and the arrangement of the striæ on the rock beneath the drift would alone disprove its origin at the hands of any body of standing water. Were each feature of the drift, and each feature of the underlying rock examined in detail with reference to the possibility of its origin at the hands of standing water as principal agent, the combined testimony of all would be found to be overwhelming against the notion of such an origin.

If seas and lakes were not principal factors in the production of the drift as a whole, it does not follow that they were not subordinate factors, or that locally they were not of great importance.

Water and Ice Co-operating.

Shore-ice or pan-ice co-operating with the water of lakes and seas.—It has already been seen that streams, even when aided by the ice which forms upon their surfaces in winter, cannot account

for the drift. It has been seen that lakes could never have covered the drift-mantled country, and therefore that the drift did not originate wholly or mainly through the agency of lakes. It has also been seen that the sea, acting alone, cannot account for the drift and its accompanying phenomena. It remains to inquire whether standing water, aided by the ice which forms, or which under favorable conditions may have formed on its surface, can account for the phenomena which water alone cannot explain. Since the distribution of the drift proves that it is not of lacustrine origin, and since lake ice is restricted to lakes, it is clear that lake ice cannot afford the key to the explanation of the drift. Yet because the action of the lake ice is more familiar than that of sea ice, it will be profitable to study it briefly.

The ice which forms upon the surface of lakes in winter may be subject to considerable movement both during the winter and in the spring. On fresh water, ice forms at a temperature of 32° Fahr. The ice thickens as the isothermal plane of 32° sinks beneath the surface. Although water expands on becoming ice, the ice cannot suffer reduction of temperature without contraction. If its temperature be lowered greatly, and that suddenly, as often happens in winter, the contraction of the ice is correspondingly great. The ice cover which fits a lake snugly at a temperature of 32° becomes too small, after contraction, to cover the whole surface of the water. It must either draw away from the shores, or crack. If the attachment of the ice to the shore is stronger than the cohesion of adjacent parts of the ice, the ice will crack. Otherwise it will draw away from the shore. Both withdrawal from the shore and cracking might take place in the same lake at the same time. The intense cold of the winter nights in temperate latitudes affords abundant illustration of both results. In whichever way they are formed, the breaches caused by the contraction of the ice will be healed by the freezing of the water which rises in them, and again the cover of ice fits snugly over the water beneath. When the temperature again rises, the ice expands. It was already large enough to cover the water, and expansion makes it too large. It therefore crowds the

shores of the lake and tends to advance upon them. Some part of the strain may be relieved by the arching of the ice, but this could not do away with shoreward pressure. Under favorable conditions, the shoreward movement may be considerable. When the shoreward movement of the ice begins, its margin may be frozen to stones of greater or less size. As it crowds upon the shore, the stones frozen to its lower surface will grind the surface over which it moves. If this surface be of material capable of receiving striæ, as limestone, it may be striated as the bowlder-bearing ice is shoved over it. Taken singly, the striæ thus produced may closely resemble those found in association with the drift. At the same time, the stones which marked the bedrock would themselves be worn after the fashion of the stones of the drift. The process of ice movement here described may be repeated many times in the course of a single season.

At the close of winter, fed by the swollen currents of streams flooded by melting snows,[1] the water in the lakes rises. The melting ice is broken into blocks. In the flooded condition of the lakes, these blocks are carried above and beyond the usual shore lines. Waves may drive them still further. Where the slopes of the shore are gentle, and the waves high, the ice may be driven many feet above the high-water shore line, and many rods beyond it. In this movement, those blocks of ice which were originally frozen to the shore sometimes carry stony materials in their bases, and, thus armed, wear the surface over which they are shoved. The ice is sometimes broken up and driven on shore during the winter as well as in the spring. Once on the shore, the ice blocks may be frozen to the land surface, to be again moved inland by the waves and crowding ice blocks of succeeding storms and floods. While it seems altogether possible that striæ may be produced both on the bedrock and on loose stones by the shoreward movement of lake ice, good examples of striæ demonstrably thus produced, and comparable to those affecting the surface of the rock beneath the drift, are not known. The vertical range of such striæ would be very limited at best, unless the level of the lake changed.

Sea water freezes at a temperature of about 28° Fahr. With respect to temperature, sea water ice is believed to behave like other ice. Although ice never covers the sea from shore to shore, except in narrow bays, fjords, etc., belts of ice of considerable width are formed on its surface in high latitudes. This ice is sometimes broken up during the violent storms of winter, and uniformly suffers this fate in the storms of spring. Thus arise blocks or "pans" of floating ice, some of which are many acres in extent. These blocks of floating ice, frozen together in larger or smaller numbers, constitute the ice-floe of the northern seas. The ice of the sea is subject to all the movements which affect the ice of lakes, and to such additional movements as the tides may bring about. Since the waves of the sea are stronger than the waves of lakes, the ice of the sea may be correspondingly more effective in wearing its shores.

The striæ produced at any given period by pan-ice or ice-floe, must be confined to the shores. As developed at any one period of time, their vertical range must be exceedingly small, and the altitude at which they occur should nearly correspond at all points about the margin of any body of water on the shores of which they are formed. A great vertical range might conceivably be given to shore-ice or pan-ice striæ, if the water level was inconstant in relation to the land. If the land along shore were to rise gradually a thousand feet, or if the sea were to fall an equal amount, it can be conceived that shore-ice might produce striæ throughout the whole vertical range between the first and last water levels, if all conditions were favorable. But even on the most liberal interpretation possible, this conception does not at all meet the case of the striæ which are associated with our drift. Not to speak of other difficulties, the systematic arrangement of these striæ (see Vol. II., p. 849) is altogether fatal to the idea that ice along any shore, or along any combination of shores, was the principal agent concerned in their production.

If it be conceived that the whole area of land covered by drift was beneath the sea during the drift period, every part of the land surface, as it emerged, must at some time have been a sea

margin. Under such circumstances, if it be assumed that the temperature was low enough to freeze the sea water to considerable depths, the shore-ice might have done all that shore-ice can ever do in the way of developing striæ. But even with so violent an assumption, the direction of the striæ would be likely to betray their origin. Striæ formed in this way would be more or less nearly perpendicular to the line of the shore on which they were formed. On the slopes of isolated elevations, as they passed through the insular stage during emergence, the striæ formed by shore-ice should run up and down the slopes on all sides. The same would be true on the slopes of mountain ranges. The striæ would thus be developed in a sort of system, a system determined by the method and position of their formation. The waves, striking the shores at different angles might seriously interfere with the regularity of the development of the system. The striæ associated with the drift are arranged systematically, but the principle underlying their arrangement is radically different from that here stated. Taken as a whole, they do not stand in any definite relationship to any existent body of water, or to any body of water which can be conceived to have existed in the past.

While therefore shore-ice may be conceived to produce striæ simulating those beneath the drift, and while certain violent assumptions, if admitted, might enable us to conceive of a widespread development of these striæ, it is still true that such ice could never have produced any considerable part of the striæ accompanying our drift. Even if this were not true, the drift possesses numerous characteristics which would make its reference to shore-ice impossible, and it fails to possess numerous other characteristics which would certainly belong to it had any phase of shore-ice been the principal agent of its production. For example, if shore-ice were the agent of the drift, the great body of it should be stratified, since it was deposited mainly in water. However effectively the action of shore and floating ice might have destroyed the superficial stratification along successive shore lines, it could not have destroyed it to any considerable depth. Again, the constitution of the drift, and the distance and

direction of its transportation, are altogether conclusive against any such conception of its origin. Shore-ice could not account for the wide transportation of the drift, since shore-ice does little more than shove about, through short distances, such materials as are already at hand. It does not transport them in quantity, widely. The topographic distribution of the drift, too, seems to put insuperable difficulties in the way of the pan-ice theory. It does not follow that standing water and shore-ice have played no part in the production of the drift because they cannot be looked upon as the principal agents concerned.

Icebergs. Icebergs emanate from glaciers. They may float out upon any lake or sea to which glaciers descend, and they may distribute themselves as widely as the conditions of temperature, wind, and water movements allow. They may carry such stony materials as the glaciers from which they originated were possessed of. This they may distribute as widely as they are drifted. We have now to enquire whether icebergs, conjointly with the water of lakes and seas, could produce the drift of the North American and European continents.

Icebergs cannot float beyond the limit of the lakes and seas on which their movements are dependent. The drift which they distribute cannot extend beyond these limits, and may fail by varying amounts, to reach them. These limits are vertical as well as horizontal. Berg drift can cover no lands which were not covered by the seas or lakes into which glaciers calved the bergs. The distribution of the existing drift by icebergs presents essentially the same difficulties, from the topographic standpoint, as its distribution by the sea. From the areal standpoint, the difficulties seem at first less overwhelming, since the southern and western limits of the drift might be thought to correspond with the geographic limits to which icebergs floated. On this hypothesis, the outer limit of the drift should be ill-defined, since very few bergs would reach the limit attained by those which went farthest. The distribution of icebergs today makes this point clear. If the drift were deposited by bergs, it should become thinner and thinner with increasing distance from its

source. If its border were anywhere marked by heavy accumulations, it should be where special topographic relations limited the movement of abundant bergs.

The border of the drift is often ill-defined, but it does not feather out to any such extent as this hypothesis would demand. The border is also frequently well defined, being marked by heavy beds of drift, and this where there is nothing in the topography or topographic relations to occasion local accumulation by means of icebergs.

When specific features of the drift, or other specific phenomena accompanying it, are examined, they are found to afford significant testimony touching the iceberg hypothesis of the drift. If it be inquired whether icebergs could striate the surface on which their drift lies, it may be answered that this could be done to a very limited extent only. An iceberg could not striate bedrock, so long as it was floating. When and where it grounded, it might produce markings upon its bed, but these could hardly be continuous for great distances. Neither would they be straight as a general rule. Bergs are likely to swerve as they ground, and any striæ they might produce would correspond with the direction of this swerving motion. Striæ believed to have been made by icebergs have been seen in a few localities, possessing the characteristics which might have been anticipated.

To be brought into existence by icebergs, the divergent systems of striæ observed beneath the drift would demand an impossible system of atmospheric or aqueous currents. Reference need only be made to the figure (Vol. II., p. 849) showing the arrangement of striæ in eastern Wisconsin. No system of air or water currents could drive the icebergs in such directions as to produce this remarkable system of striæ. Much less could there be systems of air or water currents which would occasion the repetition of the general features of this system many times within the area of drift. Icebergs would also be altogether incompetent to account for the production of striæ in many of the anomalous positions in which they occur, such as the under-

sides of overhanging cliffs, in horizontal grooves in vertical or sloping faces.

Except where icebergs grounded, any deposits they might make would be made through water. They should be largely stratified, although the type of stratification developed by the dropping of coarse and fine material through still water might be recognizably different from that developed in deposits made along shores or by running water. The type of stratification which affects the larger part of the stratified drift, is the stratification developed by rapidly moving streams. It is not the type of stratification which would be developed in material dropped through still water. Further, the relations which subsist between the stratified and the unstratified drift are not such as would exist if the drift were the work of icebergs. Were there no other insuperable difficulties in the way of supposing that icebergs were responsible for the drift, we should find it in the constitution of the drift. It will be remembered that the agents which deposited the drift at any given point, were generally agents which had gathered material all along a somewhat extended course, and that in general the larger part of the material which they left at any given point had been derived from sources close at hand. This is just the work which icebergs cannot do. They can carry such material as they possessed when they set sail, but they can gather nothing along the course of their journey.

Furthermore, if the whole of the drift-covered country were submerged, as must needs be if icebergs alone are to explain the drift, where was the land which nourished the glaciers whence the icebergs came?

From these considerations it seems certain that icebergs were not the sole or the principal agents of the drift. Were all the characteristics of the drift and all the phenomena accompanying it examined in detail, the result of their combined testimony would confirm the conclusions to which this partial examination has led. This would still remain true, even though certain features of the drift might seem to find adequate explanation in the icebergs. Since icebergs were not the sole or the principal agents

concerned in the production of the drift, it does not follow that they may not have played a subordinate part.

Neither winds, nor streams, nor lakes and seas, acting alone, can account for the drift. Neither can their combined activities, attributing to each its maximum, go far toward explaining the remarkable series of phenomena bound up in the drift, or closely associated with it. Even if shore-ice, pan-ice, and icebergs be added, the whole combination falls far short of adequacy, though pan-ice and icebergs might account for some phenomena which water and wind cannot. It is evident therefore that some other agency must have been concerned in the production of the drift, though wind and water and shore-ice and icebergs may have played subordinate rôles.

Glaciers.

A possible agent concerned in the production of the drift is glacier ice. If glacier ice be responsible in whole or in part for the drift which has so great a development in North America and Europe, the study of the results effected by glacier ice to-day should give us confirmatory testimony. It is well known that many existing glaciers increase and diminish sensibly within periods of a few years. Even seasonal fluctuations in size are readily observed. These fluctuations of accessible glaciers facilitate the study of their work, and the careful study of the results which existing glaciers effect, affords a means of testing the possibility of the glacier origin of the drift.

After a glacier has retreated for a distance up the valley which it occupies, an area which was formerly covered by the ice is left bare. The area from which the ice has withdrawn is readily accessible, and the effects of former ice occupancy and activity may be seen. In such situations, the surface is found to be more or less generally covered with a mixture of bowlders, gravel, sand and clay. If many valleys occupied by glaciers be examined, these various constituents of the surface material may be found to co-exist in all proportions. They may be in approximately equal quantities in one valley, or in one part of one

valley, while any one may predominate over all the others elsewhere. In its physical heterogeneity therefore, this stony glacial débris very closely resembles certain common phases of our continental drift. In the glacier deposits of mountain valleys, however, stony material is likely to be more abundant relatively than in our drift.

If the stones of the drift in glacier valleys be examined, a considerable variety of rock types may sometimes be found. The glacier deposits are thus seen to possess lithological, as well as physical, heterogeneity. This is a second point of correspondence between glacier deposits and the drift. If the stones in glacier deposits be studied in connection with the surrounding rock formations which are *in situ*, it is found that the stony material deposited at the foot of any particular glacier corresponds with the types of rock found along the course of the valley through which the ice has come, and further, that pieces of all types of rock represented in the course of the valley through which the ice has come, are liable to be found in the deposits left by the ice on the surface from which it has withdrawn. But in general, the lithological heterogeneity in the deposits of existing glaciers is less extreme than in our drift.

In the glacier deposits, the various constituents, ranging from huge bowlders to fine clay, may often be seen mingled together without trace of stratification, just as in our drift. But stratified deposits are by no means wanting. Beds of assorted sand and gravel may sometimes be seen to overlie unstratified mixtures of bowlders, gravel, and clay in some places, and to underlie similar materials in others. Beds of stratified material may even be inserted between beds of unstratified. In all these characteristics and relations the deposits of the glaciers resemble those of the drift.

Many of the stones of the unstratified glacier deposits possess the subangular forms, and the planed and beveled surfaces which have been noted as characterizing the stones of our drift. The stony material of the stratified drift associated with glaciers is more commonly rounded. Some of the stones left by the glacier,

especially those having subangular forms and beveled faces, are found to be superficially marked with a series of parallel lines, or with multiple series of parallel lines, each series being discordant with each other. These surface markings appear to be identical with those on the stones of our drift. As in our drift, striated stones are less common in the stratified deposits associated with glaciers, than in the unstratified.

Upon careful examination, the fine earth (clay) in which the bowlders are imbedded, is found to consist of nothing more or less than fresh particles of rock, such as might be produced by crushing or grinding the stony matter of the same deposit into fine particles. In this respect also, deposits known to be of glacier origin find close correspondence with the drift. In the glacier deposits, too, the fine material which often serves as a matrix for the imbedded bowlders may sometimes be seen to be foliated, after the fashion of the corresponding material of the drift.

The topography of the deposits made by the glaciers is similar in kind to that which characterizes much of the drift as we know it, but is developed on a less extensive scale. Except in the axes of the glacial valleys the deposits are seen to stop on a descending slope where the ice stops, or where the ice has stopped at some earlier time, leaving the higher part of the valley drift-covered, and the lower part drift-free. Along the axes of the valleys, the deposits of gravel, sand, and silt have a nearly plane surface, and extend beyond (below) the unstratified drift.

The glacier deposits stand in the same relation to the underlying rock that our drift does. Where surfaces of bare rock are exposed to observation they may be seen to be polished and striated, the striæ being parallel with each other, and with the course of the valley down which the ice has moved. Upon the most careful examination, these striations on the rock recently occupied by alpine glaciers are found to be indistinguishable from those on the rock beneath the drift in the drift-covered areas of North America and Europe. If the rock of the valley bottom be laid bare by removing the drift, its surface is seen to be firm and fresh. Any decomposed material which may once have covered it has

been swept away, as well as all that part of the rock which had been affected by the disrupting and decomposing effects of surface exposure. In all these respects, the correspondence between the deposits made by glacier ice and the drift seems complete.

So too, if knobs or bosses of rock, large or small, chance to be discovered by the retreat of the ice, they may be seen to possess the form of *roches moutonnées*, with one side worn more than the others, and that the side facing up the valley. Now and then the striæ affecting the surface of these *roches moutonnées* may be seen to be deflected from their normal course down the valley, and to be bent round the bosses, showing that the elevation influenced the details of the movement which made the striæ, without turning the striating agent out of its general course.

It is sometimes possible to go back a short distance beneath the ice itself. The many caves made by natural and human agencies afford such opportunity. Under the ice one may often be fortunate enough to see the contact of the glacier with its bed. Under favorable circumstances the lower part of the ice may be seen to be set with stones and with other materials of all grades of coarseness and fineness. The movement of the rock-shod ice is too slow to be sensible, but it is easy to see that if it move at all, no matter how slowly, it must powerfully corrade its bed. At the same time that the bed of the glacier is striated and polished, the stones in the bottom of the ice, themselves the graving tools, will suffer wear similar to that which they inflict. Not only this, but if the different parts of the ice move at different rates the stones will rub one another during the movement. As they rub against one another, or as they rub against the bed over which the ice is moving, flat surfaces as well as striations will be developed. If for any reason the stones turn in their ice-setting, as when they encounter a resistant object in the rock-bed, they may expose a new surface to planation and striation, or the old surface may be lined in a new direction, thus developing a second set of striations crossing the first. If any particular stone is turned frequently enough and rubbed hard enough against its neighbors, or against the glacier's bed, successive sets of striæ may be effaced.

Those which finally remain, when the ice has deposited its load, will be only those which were last named, or those which escaped destruction. As successive sets of striæ on drift stones are obliterated, new ones taking their places, the stones become smaller. If the process be continued long enough, a stone may be completely worn out. The product of the wear would be rock-flour. Rock-flour, the product of glacial grinding, is carried on beneath the ice, and constitutes an earthy or clayey matrix, in which the accompanying stones and bowlders are imbedded. It is identical with the "clay" in which the bowlders are seen to be imbedded on the land from which the ice has receded. It is comparable in all respects to the matrix of our bowlder-bearing clays.

If one is fortunate enough to go beneath the ice at the point where a stream issues, it may be seen that the stream, even while its course is beneath the ice, is carrying such material as its velocity enables it to transport, and that it is continually dropping parts of its load. The deposits made by flowing water beneath the ice are stratified, as the deposits of running water always are. Should the ice crowd out over the stream's bed, as is possible, displacing the water in the operation, such parts of the stratified deposits as were not ground up and borne away by the ice might be buried beneath the unstratified deposits which it might make. Since this process of change may be repeated, ice succeeding water, and water ice, at any given point, we discover at least one way in which alternations of stratified and unstratified deposits may be brought about in connection with glacier ice.

The flowing water beneath the ice does not stop with the terminus of the glacier itself, but issues as a swift river, hurrying on down the valley, with such load of sediment as it can carry. These materials are spread out in alluvial plains beyond the edge of the ice, wherever the stream is unable to carry them further. Considerable plains of stratified material have been built up in this way by the ice-born rivers, beyond the ends of many alpine glaciers. In some cases they extend many miles down the valleys, the coarser materials being near the ice and the finer further away. In every essential particular concerning constitu-

tion, structure, form and relationship, these valley plains resemble the many valley deposits of stratified drift, which stretch beyond the unstratified drift in our own country and northern Europe.

All these considerations make it clear that there are many points in common between the deposits made by alpine glaciers, and the drift of the continental areas. Indeed, the correspondences between the two formations are so close, so numerous, and comprehend so many phenomena related to one another in intimate and nicely adjusted ways, that it is difficult to see how they could have been brought into existence by any other than identical agencies.

The physical heterogeneity of glacier deposits considered in relation to the sources whence their materials were derived; the lithological heterogeneity of these deposits likewise considered in relation to the sources whence the materials came; the sizes, shapes, and marking of the coarser parts of these deposits; the physical and chemical condition of their finer parts; the stratified, unstratified, and foliated structures of the various parts of these deposits in their relations to one another and to topography; the relation of these deposits to the rock upon which they rest; the frequent termination of the unstratified parts on declining surfaces; the extension of the stratified parts far down the valleys beyond the unstratified parts; the topographic relations of these deposits and their own topography; the systematically disposed striæ on the rock beneath them, taken in connection with the direction in which materials have been transported; the shapes of the hills worn by glaciers, and the relation of these forms to other associated phenomena; the general surface expression of the region worked over by a glacier, in contrast with adjacent regions which have been so affected; all these phenomena, so peculiar, so distinctive, and particularly all these phenomena in their manifold, and intricate, and peculiar, and nicely adjusted relations, afford a remarkable series of criteria for the recognition of glacier deposits, even in regions which now possess no remnant of ice.

The various marks left by glacier ice on the bed over which

it has moved are so many and so distinctive, and stand in such nicely adjusted relations to one another, that it hardly seems credible that any second agency or combination of agencies could produce results so similar as to be mistaken for them, if all the foregoing characteristics and relations are clearly developed and open to observation. It is not to be understood that all the marks of glacier deposits, or all the phenomena accompanying them, are always present at every point, or within any circumscribed area where glacier ice has been. The study of considerable areas of glacier deposits may sometimes be necessary for the recognition of all the features and relations referred to. Some, or even many of them may altogether fail of development in a given locality. Those which are developed may be but feeble. In a limited area of drift where relations are not discernible, or where many of the various characteristics referred to above are but poorly developed, or where they are not open to observation, glacier deposits might be confused with those produced by certain other agencies, especially if the region in question be one where glacier ice is not known to have been. If a glacier deposit be very ancient, it may have lost, by decay, most of its diagnostic characteristics; or, since its origin, it may have suffered alteration, with the effacement of its distinctively glacial marks, at the hands of some geological agent other than ice. It is not to be understood, therefore, that glacier deposits can always and everywhere be recognized at sight, especially in a region where glaciers do not exist, and where they are not known to have existed. But it is confidently believed that any series of typically developed glacial deposits which have suffered so little change that they still preserve the characteristics which the ice impressed upon them, cannot fail to give evidence of their origin, if their characteristics and relations are open to observation.

If glacier ice alone be responsible for the drift, it is necessary to suppose that the whole of the drift-covered area was overspread by an ice-sheet. Alpine glaciers are so small and so connected with mountains, that studying them alone, it seems

incredible, at first, that any extension of such glaciers could be great enough to account for the drift deposits of so great areas as those of North America and Europe. Fortunately, our knowledge of glaciers and of glacial phenomena is not restricted to Switzerland, or even to the type of glaciers which has been termed alpine. Larger bodies of land ice exist in various parts of the world. The largest of these which has received even a small amount of attention is the ice cap of Greenland. But this is accessible only with difficulty, and has received little attention compared to that which has been bestowed on many mountain glaciers. While, therefore, the Greenland ice-sheet might afford a closer analogy to a continental ice cap than alpine glaciers do, it has not been sufficiently studied to give us so reliable a point of departure in the discussion of the subject, as the smaller glaciers. But it is so large, and departs so far from the alpine type of glacier, as to give us an enlarged idea of the dimensions which glacier ice may attain, and of the results which it may accomplish. Switzerland has an area of about 16,000 square miles. It is said to harbor 471 glaciers, 138 of which are more than four and three-fourths miles long.[1] According to official surveys, the 471 glaciers, and the snowfields associated with them, have a total area of a little more than 700 square miles. The estimated area of the ice cap of Greenland is about 300,000 square miles, an area nearly nineteen times as great as that of all Switzerland, and about 422 times as great as that of the united area of all the Swiss glaciers and snowfields.

The drift of North America is estimated to cover an area of about 4,000,000 square miles,[2] an area only a little more than thirteen times as large as the area of Greenland's ice sheet. Stated in the form of ratios, therefore, the snow and ice-covered area of Switzerland is to the snow and ice-covered area of Greenland as 1 is to 422; while the snow and ice-covered area of Greenland is to the North American area of drift as 1 to 13. The ratio between the entire snow-covered area of Switzerland and the

[1] Heim, Handbuch der Gletscherkunde, 1885.

[2] Upham: Appendix to Wright's "The Ice Age in North America."

area of the ice cap of Greenland is, therefore, much greater than that between the latter and the drift-covered area of our continent. From the standpoint of ratios, it is an enormously greater jump from an alpine glacier to the ice cap of Greenland, than from the ice cap of Greenland to such an ice sheet as must have covered the northeastern part of our continent, if the drift be the product of glacier ice. If the comparison of the three areas be made without resort to ratios, their relative sizes are expressed approximately by the following numbers: 1, 422 and 5634.

But even Greenland does not possess the greatest ice sheet known. The Antarctic continent—for this land and ice mass seems to merit the name of continent—is almost completely covered with ice, so far as known. While its area has not been determined with accuracy, it has been recently estimated to contain at least 4,000,000 square miles,[1] that is, an area equal to the great sheet of drift of North America, an area twice as great as that of the drift which mantles northwestern Europe. The existence of so great an ice sheet today makes it easier to think of the existence of an equally extensive ice sheet elsewhere in the past. It removes the element of incredibility which, at first thought, seems to attach to so striking a theory as that of the glacial origin of the drift. From the standpoint of knowledge concerning ice sheets, the glacier theory is a possible theory, but it is not to be understood that the existence of an Antarctic ice sheet, equal in size to the area of North American drift, is any argument for the glacier origin of our drift. It is more difficult to account for the existence of an ice sheet in temperate than in frigid zones. But in spite of the difficulty, our study of the drift has led us to the conclusion that glacier ice was the principal agent concerned in its production.

Glaciers and Icebergs Co-operating.

Granting that glacier ice was the principal agent of the drift, may it not still be true that other agents were concerned in its production? If so, to what extent? It is well known that the

[1] Murray. Proceedings of the Royal Geographic Society. 1894.

earth's surface is subject to movement. Considerable areas are known to undergo slow elevation, while other adjacent or distant areas are suffering subsidence. If, during the drift period, glaciers formed somewhat extensively on the higher lands now covered by the drift, it might be conceived that a moderate subsidence would allow ice to float out from the glaciers of the higher lands over the waters covering the intervening lower areas, thus distributing the drift over them. That is, the drift might be thought to be the joint product of glaciers and icebergs, glaciers working on the higher lands and icebergs over the lower. Conjecturally, the relative importance of these two agents might vary greatly, but the glaciers must have remained sufficiently extensive to give rise to the ice of the icebergs. But unless it attributed the chief work to glaciers, such a combination hypothesis as this seems open to fatal objections. We have already seen what icebergs can do, and that some of their results may simulate those of glacier ice.

On the hypothesis that icebergs were an important agent in the production of the drift of the lower lands, it would be expected that the distinctively glacial marks would be absent from the lower drift-covered lands, especially near the outer borders of the drift. But this is not the fact. Marks of one sort or another which seem to be distinctively glacial, occur down to the level of the sea, near the southern border of the drift. Among such markings, the striæ on the trap rock south of Jersey City may be mentioned. At various other points too, as in Southern Illinois, at or very near the extreme margin of the drift, striæ are found beneath deposits which appear to be strictly glacial. While admitting that berg deposits may locally closely simulate those of glaciers, we cannot admit that icebergs can produce such striæ as are found near the margin of the drift at many points, even at altitudes scarcely above the level of the sea.

On the hypothesis which we are here considering, too, it would be expected that the position of the southern border of the drift was determined by icebergs, not by glacier ice. We have already seen that both the topographic relations of its terminus, as well

as its inherent character, preclude this belief. From the quantitative standpoint also, the drift border is not always such as would have been produced by icebergs. The drift is often too thick along its border and that in situations where there could have been no shore, and therefore no exceptional accumulation of berg deposits to refer it to icebergs. Like other parts of the drift, the border is made up of materials which were largely gathered close at hand. The glacier ice itself, or some agent capable of accomplishing results which have not been distinguished from those of glacier ice, reached the approximate, and often the exact southern border of the drift-covered area. Further, the character of the drift and its accompanying phenomena indicate that the same forces which were operative on the higher lands in the production of the drift, were operative on the lower also. There is not a higher body of drift of one sort, and a lower body of drift of another sort, as this hypothesis would demand.

Nevertheless, nothing which is here said precludes the idea that lakes of lesser or greater magnitude may have been associated with the ice sheet for longer or shorter periods of time at one stage and another of its development. If such lakes existed, iceberg deposits were doubtless made in them. Berg deposits were doubtless likewise made wherever the glacier ice reached the sea, and since the coastal regions may have been lower than now, it is altogether possible that some of these berg deposits were made on areas which are now land. The foregoing considerations seem only to preclude the attribution of any large part of the drift to bergs, or to floating and grounding ice.

Glaciers and pan-ice.—Any conditions which would allow of the co-operation of glaciers and icebergs, would also allow of the co-operation of pan-ice. If the coastal regions were lower than now, while ice covered that part of the drift area which was not submerged, shore ice might have been operative over a narrow belt determined by the position of the shore line. Since the shore lines must have varied with varying altitudes of the land, ice-floe and other forms of shore-ice may have operated at

one time and another over all that part of the land surface which was submerged during the drift period. If the amount of submergence during the drift period could be determined, we should have the maximum measure of the extent of the operation of pan-ice. Pan-ice might produce results closely simulating certain results produced by glacier ice. On the glacier-pan-ice combination hypothesis, too, it is possible that any region affected by pan-ice at one time may have been affected by glacier ice at an earlier time, and that the effects of the glacier ice were not wholly obliterated by the pan-ice. On the other hand it is conceivable that a zone affected by pan-ice at one time was subsequently elevated and covered by glacier ice which may have partly or even wholly obliterated the effects which the pan-ice had produced.

The results which shore and pan-ice acting alone can effect, have already been studied. That both were operative about the shores of the land which the glacier ice covered during the drift period cannot be doubted, any more than can the existence of icebergs. The question of the relative importance of pan-ice and glacier ice in the production of the drift is a question concerning which there is much difference of opinion.

Except along the coast lines and along the shores of lakes pan-ice could not have been operative. Away from the coasts, therefore, little can be ascribed to it. This removes the larger part of the drift area of the United States from the zone where shore or floating ice in any form can have been long effective. Along the southern part of the drift-covered coast of the United States there is no conclusive evidence of subsidence during the drift period. Further north, subsidence seems to have been a fact, and shore ice was doubtless a more considerable factor. It is not without significance that the Canadian geologists attribute much more importance to pan-ice than do the geologists of the United States. Some of them ascribe to it a work comparable in importance to that which the glacier ice effected.[1] But the difference in views is perhaps one of degree rather than of

[1] Sir J. William Dawson. The Canadian Ice Age. 1893.

kind. The glacial theory involves the co-operation of pan-ice as well as icebergs, or at least recognizes the possibility of this co-operation. At the close of the drift period the relative importance of the results of pan-ice must have depended partly on the vertical range of its activity as determined by changes of relative level of sea and land, and partly on whether the glacier ice subsequently over-rode the zone of the early activity by the pan-ice. The known facts concerning the relative changes of level of sea and land, and the known facts concerning the nature of the drift itself, seem to ascribe by far the larger part of the work involved in its production, to glacier ice. The functions of other forms of ice seem to have been very subordinate.

Significance of the abundance of stratified drift. The fact that so much of the drift is stratified has sometimes been thought to be a difficulty in the way of the glacial theory. It is certainly true that the deposits made by glaciers directly are unstratified; it is certainly true that a very considerable portion of the drift is stratified. But it is to be remembered that the ice of every extinct glacier, be the same large or small, was converted into water upon its dissolution. It is to be remembered that as the ice of any glacier moved forward during the period of its growth, it was constantly melting, so that, barring the loss by evaporation, all the ice of any glacier, from its inception throughout the whole period of its history to final dissolution, was converted into water, and that most of this water ran for longer or shorter courses over the surface of land, either beneath or beyond the ice, often modifying the surface of the drift already deposited by the ice, and often depositing upon it, in bedded form, such gravels, sands, and silt, as fell to its lot to carry and deposit. If northern North America and Europe were covered by huge ice caps, as the glacial theory of the drift supposes, every pound of these stupendous ice masses which did not evaporate was sooner or later converted into water. According to the glacial theory, therefore, the amount of water which was operative jointly with the ice in producing the drift, must have been nearly as great as that of the ice itself. It follows that the glacier theory of the drift not

only allows, but even demands, that a large part of the drift be stratified. It demands that the water issuing from the ice should carry beyond it such products of the glacial grinding as its currents were able to handle. This is exactly what is taking place in glaciers today, and the stratified valley drift extending beyond the great body of unstratified, argues that this is what took place when our drift was deposited.

In searching for the explanation of the drift, therefore, if the facts concerning the drift and its relations are before us in their fullness, it would seem that there is little room for doubtful theorizing. Geologists are now very generally agreed that glacier ice, supplemented by those other agencies which glacier ice calls into being, is the only geological agent which could have produced it. But it is here repeated that this does not preclude the belief that at various times and places, in the course of the ice period, icebergs may have been formed, or that locally and temporarily they played an important rôle. It does not preclude the idea that wherever icebergs existed, berg deposits may have been made. It does not preclude the idea that pan-ice may have been an important factor locally. It does not preclude the idea that, contemporaneously with the production of the great body of the drift by glacier ice, the sea may have been at work on some parts of the present land area, modifying the deposits made by ice and ice drainage. Indeed, there is abundant evidence that such was the fact. There is abundant evidence that in some regions now covered by drift, the land stood lower than now, or the sea higher, when the drift was deposited, or since.

The glacial theory does not deny that rivers produced by melting ice were an important factor in transporting and depositing drift, both within and without the ice-covered territory. It does not deny that lakes, formed in one way and another through the influence of the ice, were locally important in determining the character of the drift. Not only does the glacier theory deny none of these things, but it distinctly affirms that rivers, lakes, bergs, and pan-ice must have co-operated with the glacier ice, each in its appropriate way and measure. ROLLIN D. SALISBURY.

Editorial.

The winter meeting of the Geological Society of America held at Baltimore December 27, 28 and 29 was largely attended, and marked interest was manifested in the papers presented. The foremost thought of all on assembling was the irreparable loss the Society had sustained in the death of Professor G. H. Williams, to whose interest and influence the holding of the session at Baltimore at this time was chiefly due; and the first act of the Society, after the usual opening addresses and preliminary business, was to pay a fitting tribute to his memory. A very graceful and appreciative sketch of his life and labors was presented by Professor William B. Clark, to which several members of the Society who had been most intimately associated with Professor Williams added earnest and sympathetic expressions of their esteem and admiration. An appropriate memorial to Amos Bowman was presented by his colleague of the Canadian Survey, Mr. H. M. Ami.

The program embraced forty-eight titles. With a very few exceptions — and these in part due to illness — the authors of the papers were present and the papers actually read and discussed. The habit of sending in titles of papers yet unborn, and of appearing by name but not in person, has fortunately found little expression at the winter meetings of the Society, and at this session was reduced to a minimum.

The distribution of subjects is worthy of study as indicating the drift of interest and activity. About 18 per cent. of the papers may be classed as predominantly structural. It was notable, however, that in a large number of these, the structural features were but an obvious groundwork for dynamical inferences. Very few were simply descriptive in purpose, though the authors rarely pressed conclusions, preferring apparently to leave

the inferences to enforce themselves. Of purely dynamical papers there were scarcely 5 per cent. though the dynamical factor was obviously a vital element in a large percentage of the other papers. Of papers treating of regional geology there were about 6 per cent. and of formational geology about 15 per cent. The petrological group was *facile princeps*, leading all other classes by a wide margin, and constituting nearly one-fourth of the whole. Glacial titles embraced one-sixth of the whole; the palæontologic and the physiographic, one-twenty-fourth each; while chronology and nomenclature were represented by one paper each.

The over-crowded state of the program was happily relieved by the formation of a temporary subsection of petrology before which the technical petrographic papers were read, while those that embraced structural and dynamical phases of general interest were presented to the whole society. This is a precedent which will doubtless be followed to advantage in the future.

The following is a list of the papers presented:

On certain Features in the Jointing and Veining of the Lower Silurian Limestones near Cumberland Gap, Tenn. *N. S. Shaler.*

The Appalachian Type of Folding in the White Mountain Range of Inyo Co., Cal. *C. D. Walcott.*

New Structural Features in the Appalachians. *Arthur Keith.*

The Faults of Chazy Township, Clinton Co., N. Y. *H. P. Cushing.*

The Formation of Lake Basins by Wind. *G. K. Gilbert.*

The Tepee Buttes. *G. K. Gilbert* and *F. P. Gulliver.*

Remarks on the Geology of Arizona and Sonora. *W J McGee.*

Geology of the Highwood Mountains, Montana. *Walter H. Weed* and *Louis V. Pirsson.*

Genesis and Structure of the Ozark uplift. *Charles R. Keyes.*

The Geographical Evolution of Cuba. *J. W. Spencer.*

Recent Glacial Studies in Greenland (Presidential address). *T. C. Chamberlin.*

Observations on the Glacial Phenomena of Newfoundland, Labrador and Southern Greenland. *G. Frederick Wright.*

Highland Level Gravels in northern New England. *C. H. Hitchcock.*

Variations of Glaciers. *Harry Fielding Reid.*

Discrimination of Glacial Accumulation and Invasion. *Warren Upham.*

Climatic Conditions shown by North American Interglacial deposits. *Warren Upham.*

PUBLICATIONS.

Report on the Geology of the Coastal Plain of Alabama, Geological Survey of Alabama (pp. xxiv–759). By EUGENE ALLEN SMITH, State Geologist, Montgomery, Ala., 1894.

This report, which treats of all the post-Palæozoic formations of Alabama, is one of value. It deals with matters which are of importance in themselves, and it deals with them in an intelligent way. The matter is so presented that those who are interested in the conclusions only, can find them without laboring through the details, while those whose interests lie in such directions as to make details valuable, will not be disappointed. It is interesting to note that Dr. Smith has conformed to the recent practice of some other state geologists in prefacing his report by an introductory chapter which is intended to make the body of the report intelligible to readers who are not geologists. This practice is to be especially commended in state survey reports. Had it been in vogue since the beginning of state survey publications, geological reports would have been much more widely read, and read with much more understanding and interest by the citizens of the states for whom they are or should be intended. It would appear that the coastal plain formations of Alabama have been worked out with so much detail that in the future Alabama is likely to be the starting point for the correlation of many of the coastal plain formations in the gulf region. The formations and their relations are shown in the following table:

POST-TERTIARY OR QUATERNARY.

Recent.

1. Coast sands and alluvium, upper part of the Biloxi — 10 to 100 ft.
2. First bottoms and other alluvial deposits of the streams.
3. Soils and rainwash.

Pleistocene.

1. Coast deposits, lower part of the Biloxi, coastal — 150 to 200 ft.
2. Mobile Bay formation. (Mon Louis Island), estuarine, undetermined.
3. Second bottom terraces of the rivers, undetermined but over 60 ft.
4. Ozark or Conecuh sands. Sand terraces — undetermined.

1. Third Terraces of the rivers (surface deposits)	10 to 20 ft.
2. The Lafayette mantle (Orange Sand, Appomattox)	25 to 200 ft.

TERTIARY.

Miocene.

1. Pascagoula	Thickness undetermined, about 200 ft.
2. Grand Gulf	" " at least 500 ft.

Eocene.

1. St. Stephens, White Limestone (Vicksburg and Jackson)		200 to 350 feet.
2. Claiborne		450 "
a. Claiborne proper	150	
b. Buhrstone	300	
3. Lignitic		825 to 850 "
a. Hatchetigbee	175	
b. Bashi or Wood's Bluff	80–85	
c. Tuscahoma or Bell's Landing	140	
d. Nanafalia	200	
e. Naheola or Matthew's Landing	130–150	
f. Sucarnochee or Black Bluff	100	
4. Clayton. (Midway)		25 to 200 feet.

CRETACEOUS.

	West Ala.	East Ala.
1. Ripley	250–275	1000
2. Rotten Limestone or Selma Chalk	1000	000
3. Eutaw	300	300
4. Tuscaloosa	1000	500

The tracing out of the several formations has made it possible to determine with some accuracy, not only the periods and phases of oscillatory movement of the southern part of the state, but also the deformations which accompanied these movements. Hardly anywhere else along the coastal plain region have we such explicit data concerning Cretaceous and post-Cretaceous movements.

As will appear from the preceding table, a distinction is made between the Recent and the Pleistocene formations, but no sharp line of division is drawn. The coastal portion of the Recent series is found to be continuous below with what is classed as Pleistocene, the two together constituting the Biloxi formation. The division between the Recent and the Pleistocene is therefore in the midst of a conformable series.

The second bottom terraces of the rivers is a fluviatile Pleistocene formation, which at Mobile Bay grades into a deposit of estuarine

origin — the Mobile Bay formation. Traced seaward this formation becomes continuous with the Biloxi, or at least with its lower part. The first, second, and third formations assigned to the Pleistocene in the above table, are therefore the fluviatile, estuarine and marine subdivisions of the same formation.

Five to ten feet above the second bottom terraces, there is another series of sand terraces (No. 4 of above table) along the main streams. From their position these terraces appear to be somewhat older than the second bottom terraces. Along the minor streams, the sand terraces appear to be the main terraces. Sand similar to that of which these terraces are composed covers some of the inter-stream areas and divides, up to altitudes of 100 feet. This is the Ozark or Conecuh sand. This inter-stream sand is compared to the inter-stream phase of the Columbia, as developed at other points on the coastal plain, especially farther north. While therefore the first three of the Pleistocene formations, as shown in the table, are essentially equivalent, the fourth seems to be somewhat older.

Along the principal streams there are "third terraces" which are 50 to 100 feet above the second bottoms. These third terraces consist of red loam with more or less gravel beneath it. Their constitution is in all respects comparable to the constitution of the Lafayette formation, as developed at higher levels. These third terraces sustain the same relation to the Lafayette formation which covers the inter-stream areas, that the sand terraces (No. 4) do to the Ozark or Conecuh sand, though the third terraces and the Lafayette lie at higher levels than the sand terraces and the Ozark and Conecuh sands. The third terraces are very much wider than the second bottom terraces, and are, as all their relations show, considerably older.

The Lafayette formation finds its normal development above the third terraces. Dr. Smith's suggestions concerning the origin of this formation are of interest, and his classification of the same should be especially noted, in view of the fact that he has recently been quoted[1] as holding that the Lafayette is Pleistocene. His words are as follows:

"The general appearance of the formation, and the demonstrably great amount of erosion which it had suffered before the deposition of the undoubted Pleistocene beds, would lead us to conclude that a long period of time and important physical changes occurred between the accumulation of the Lafayette and the Pleistocene deposits. For these reasons, the weight of evidence

[1] UPHAM. Am. Nat. Vol. XXVIII., p. 979, 1894.

appears to be in favor of classifying the Lafayette as the upper member of the Tertiary (Pliocene) formation, and so I have represented it on the geological map of the state" (p. 81–82).

This would seem to be sufficiently explicit, were not some doubt thrown on this correlation in other connections. Thus we find the following :

"The great amount of erosion which took place after the deposition of the Lafayette, and before that of the next overlying deposits, has been urged as an objection to the placing of the Lafayette in the same category with the Pleistocene, but the same objection might, with equal force, be urged against classifying it with the Tertiary, since an equally great, if not greater, amount of erosion occurred between the deposition of the Miocene beds and those of the Lafayette" (p. 82).

This last statement is certainly a little curious. If the alternative were between classifying the Lafayette as Pleistocene or as Miocene, the point here made would have force. But this is not the alternative, and Dr. Smith does not really so regard it, for he classifies the Lafayette, not as Miocene or as Pleistocene, but as Pliocene. If the argument of the last citation had been urged as a reason for separating the Lafayette from both the Pleistocene and the Miocene, making it Pliocene, as Dr. Smith has really done, it would seem weighty. To use this argument for the purpose of raising the question as to whether the Lafayette is not really Pleistocene, is to take the position that an unconformity may be admitted in the Pleistocene, but not in the Tertiary. It is to take the position that different members of the Pleistocene may be much more sharply separated from each other than Pliocene from Miocene. This is a position which we believe to be untenable. The above citation does not seem to the writer to have weight against the classification of the Lafayette as Pliocene, for it is not clear that there may not have been an erosion interval between the Miocene and the Pliocene. It is true that unconformities are known in the extra-glacial Pleistocene, but they are much less considerable than the unconformity above the Lafayette. Of much more significance, in the judgment of the writer, is the constitution and physical condition of the Lafayette. Dr. Smith says: "As yet the existence of material of glacial origin among the Lafayette beds, seems not to have been proven beyond question" (p. 81). This does not seem to quite express the true condition of things. The Lafayette beds have been widely studied by many observers. Not only has glacial material not been proven to

exist in them, but in the most northern areas of the Lafayette, as shown by numerous exposures, glacial material has been shown to be absent. This is no more than negative evidence against the Pleistocene age of the Lafayette; but the volume of negative evidence is so great that it has carried conviction to every geologist, so far as we know, who has studied critically both the glacial drift and the Lafayette formation.

Concerning the origin of the Lafayette, Dr. Smith appears to incline to the view which has been advocated by McGee, viz., that the Lafayette materials were deposited during submergence of the region which they cover. In this connection a new suggestion is made concerning the relation of the third terraces noted above, to the body of the Lafayette. The suggestion is that in the emergence of the land on which the Lafayette had been deposited, the rivers flowing down over it brought in new material from the north, in this way, perhaps, adding a land accumulation to the marine accumulation which had already been made. It is suggested further, that in the course of time these streams came to be confined in more or less well-defined valleys of their own development, and that at some stage during the uplift, there was a halt of such duration that the broad valleys which these streams occupied were filled up by the streams to the level of the third terraces. This would make the third terraces "the last episode of the Lafayette drama." As the valleys were filled, the coarse materials lodged first, and the fine later, thus giving the relations which are found to exist. Dr. Smith points out very distinctly that these third terraces of Lafayette-like material do not grade into the second terraces, as has sometimes been supposed.

A good deal that is new appears in connection with the Miocene. Two distinct divisions of the Miocene are recognized. The uppermost is the Pascagoula, which has a thickness of something like two hundred feet. It is composed mainly of clays, with more or less green sand. Below this lies the Grand Gulf formation, the age of which has been definitely fixed as lower Miocene.

The data of this report concerning the Eocene have been largely published before in Bulletin 43 of the United States Geological Survey. The present report proposes some modifications in the classification there given, and publishes some new facts, the result of recent field work.

The average seaward dip of the Tertiary formations is said to be twenty-five to thirty feet per mile. Even these young and, on the

whole, regularly disposed formations are not free from considerable deformations. A fault has been found in the western part of the state, having a vertical throw of at least 200 feet. Two distinct and broad, though rather low, anticlines have been found in the same region. Both of them have a northwest southeast course. Neither of them appears to have affected the drainage of the region where they occur.

The subdivisions of the Cretaceous are given above. It is worthy of note that the four subdivisions of the formation which occur in the western part of the state cannot all be carried across to the eastern border, the two uppermost members, the Ripley and the Rotten Limestone, losing their distinctness. The name *Selma Chalk* is proposed as a substitute for the old name "Rotten Limestone," and it is to be hoped that the change may be generally adopted.

In connection with the Cretaceous, it is pointed out that the Tuscaloosa is probably the equivalent of the Amboy (Raritan) clays of New Jersey, and that this formation seems to hold its character from Massachusetts to Alabama. Judged from the physical standpoint, the other members of the Cretaceous of Alabama cannot be said to have much in common with their northern equivalents.

Many details are given concerning the palæontology of the formations described. The microscopic fossils, as well as the larger ones, have received a considerable measure of attention.

Through the whole series of the Cretaceous, Tertiary and Pleistocene formations of Alabama, the influence of the Mississippi River has been felt, a large part of the coastal plain region of Alabama coming within the great Mississippi embayment of these periods. The rivers which cross the coastal plain are all of recent origin.

The later part of the volume is occupied by county descriptions which possess a local interest, and give many sections which will be of value to students of coastal plain geology, since they will offer a basis for classification and correlation.

The economic resources of the coastal plain region are not neglected. This part of the state is far less rich in economic products than the northern part, where the great iron and coal industries flourish. Nevertheless the phosphates and clays of the central and southern parts of the state are of value, and when more extensively used the former seem destined to have an important bearing on the agricultural welfare of the state.

The phosphates are found at several horizons, but the most impor-

tant are at or near the base, and at the top of the Selma Chalk. The phosphate-bearing member at the base of the series is known as the "Eutaw, Hamburg, Selma Belt" because it is well developed at those places. For a similar reason the phosphate-bearing member at the top of the series is known as the "Livingston, Fort Deposit, Union Springs Belt." In limited quantities phosphates have also been found in other parts of the same formation. Each of the principal phosphate horizons consists, not of one stratum, but of several different strata containing phosphates in various forms. They are extensively developed throughout the Cretaceous area, from the northwest part of the state to the Georgia border.

The phosphates at the base of the Selma Chalk occur as nodules and phosphatic casts of fossils, as phosphatic sands and glauconites, or as calcareous marls containing more or less phosphate. The nodules are associated with numerous worn and rounded casts of Cretaceous fossils, such as ammonites, baculites, nautili, etc., which are also often highly phosphatic, as well as with many sharks' teeth and bones of saurians. These nodules and fossils are enclosed in a soft, calcareous matrix, and sometimes in glauconite. The nodules and some of the fossil casts are the richest phosphates found, and often contain from 40 per cent. to over 80 per cent. phosphate of lime. The phosphatic sands, glauconites and marls are much lower grade, containing from 1 to 20 per cent. of phosphate of lime, and often averaging not over 1 to 3 per cent., but they are in much larger quantities than the nodules. The phosphates of the "Livingston, Fort Deposit, Union Springs Belt," are similar to those of the lower horizon.

The Tertiary strata, as well as the Cretaceous, sometimes contain phosphates, but they are less abundant, and are of lower grade. They occur mostly in the Lignitic, White Limestone and Claiborne members of this series, and are in the form of scattered nodules and phosphatic marls.

It is shown that the phosphate deposits occur along lines of non-conformity, and that the fossil casts, etc., are all more or less worn. Professor Smith supposes the presence of the phosphates to be due to the phosphatization of fossil casts, marls, limestones, etc., during the formation of these non-conformities, and the source of the phosphates he ascribes to the decay of animals and plants, and of phosphate-bearing rocks. He shows that though the phosphate localities rarely possess sufficient quantities of high-grade material to be profitably shipped, yet the

phosphates and phosphatic marls are of great use to the farmer in the vicinity. The purely calcareous marls are discussed, and their value shown. The clays for pottery, brick and tile making are also briefly treated, and some of them are shown to be of good quality.

Dr. Smith's work has been carried on unostentatiously for many years. The present volume is not the first piece of good work which he has done. The large results which he has brought out are altogether incommensurate with the meager appropriations which have been at his disposal. While the co-operation of the United States Survey has been of much service to his work, a service which he fully acknowledges, much credit still belongs to the state geologist himself.

ROLLIN D. SALISBURY.

Dr. K. v. Chrustschoff, Ueber Holokrystalline Makrovariolitische Gesteine. Memoires de L'Academie Imperiale des Sciences de St. Petersbourg, VII. Série, Tome XLII., No. 3. St. Petersbourg, 1894. 4to, 244 pp., 3 plates and 37 figures.

The author in his introduction refers to the work already done on the subject, and shows how in the case of the true variolite ("an endomorphic contact phenomenon of diabase") the consideration of the origin is simple in comparison with the genetic history of the orbicular structure in holocrystalline, eugranitic, plutonic rocks. The origin of these are entirely different.

Finding the references to these holocrystalline orbicular rocks to be unavailable he collected them and presents a bibliography of the special studies on spheroidal building, orbicular granites, diorites, gabbros, and diabases.

As the most direct means of approaching the subject Chrustschoff chooses six of the more noted occurrences of variolitic rocks, along with four new occurrences (two in Sweden, one in Silesia, and one in Siberia), making ten, which serve as the subject of discussion for the volume. With each example the author carefully analyses the varioles into an inner core (kern) and various concentric rims (calotte) which may or may not possess radial arrangements in conjunction with their neighbors. The mass of the rock and each of these divisions is in turn studied carefully, and the optical characteristics, order of sequence in crystallization, and very frequently the chemical composition of the various constituents are discussed in detail.

Considered separately the author reaches the following conclusions:

1. Variolitic granite from Altai, Siberia (new locality).

The chemical and mineralogical compositions of the granite magma, the core and the shells of the varioles are such that they show that here is an endogenous contact formation, since the core is more basic and does not belong to the granite magma. Judging from the zircons[1] the core "is the last remnant of an inclusion of the nature of biotite-gneiss resorbed by the granite." Further, "as when a crystal of a salt is suspended in a saturated solution of salts the salt, like the crystal, is the first precipitated and then the others, so if orthoclase were caught up in the magma the orthoclase of the magma would crystallize first, then the isomorphous plagioclase." By this time the feldspar exerts only a directing influence, so that the biotite crystallizes and is oriented with regard to the feldspar interior.

2. Variolitic amphibole-granite from Rattlesnake Bar, California.[2]

The dark green rock which contains the spheroids consists of a granular mass of cloudy gray feldspar, pellucid quartz, and abundant brownish green hornblende. The varioles are more or less regular ellipsoids with diameters of 8 cm., 5 cm., 6.5 cm. respectively, and represent basic inclusions of a foreign rock, or a more basic primary secretion from the amphibole-granite magma, which have been resorbed in part by the magma. As the cooling, pressure, water contents, etc., changed, a new crystallization took place about the included remnant forming a concentric layer of minerals produced from the preëxisting magma saturated with the included substance. This action continued until the circumstances existing in ordinary granitic formations had gained the upper hand.

The spheroidal form tends towards a more rapid crystallization, and so the secretion of concentric layers follows more rapidly than the individualization of the surrounding granitic magma. From the already formed core go out certain directing influences so that the amphibole, the ores, and part of the feldspar force themselves into a radial arrangement.

3. Variolitic granite from Kunnersdorf, Silesia (new locality).

The granite mass, in which the 8–15 cm., rounded to angular spheroids lie, consists of reddish gray, medium fine-grained feldspar,

[1] Vid. Chrustschoff, Zur Kenntniss der Zirkone in Gesteine. Tschermak's Min. und Petr. Mitth. Bd. XII., p. 423.

[2] Vom Rath: Sitzungber. d. niederrh. Ges., December, 1884.

quartz, silver-gray muscovite, and biotite. The spheroids were formed in the following way:

During the eruption of the granitic magma fragments of a foreign granitic rock were surrounded by the granitic magma. The solid granite may have been "foreign" or it may have been from the already solidified portions of the magma. Resorption began and continued until the magma was supersaturated and the temperature lowered to a point where a new crystallization could begin.

The included granite consisted of orthoclase phenocrysts in a fine-grained groundmass which was more readily dissolvable than the compact feldspar. Though the phenocrysts did not remain entirely unattacked they were not completely resorbed, and an outer mixed zone was formed between them and the individualized magma. The subsequent crystallization took place in the mixed zone under the orienting influence of the feldspar. At the moment when crystallization reached the outer zone of influence the whole magma crystallized to a panidiomorphic-granular mixture.

In this case, as in the first, the character of the zircons proved a valuable aid in the interpretation of the varioles' genesis. The main mass and the core carried zircons of different habits, while the shell of the variole carried both types.

4. Variolititic granite from Ghistorrai near Fonni, Sardinia.

As in the cases above cited fragments of different rocks were surrounded and taken into the granitic magma, where their constituents were disassociated and in part resorbed. From this simple proposition it would seem that the rocks under consideration would be other than rare; there are, however, certain conditions essential to "kugelbildung."

"The inclusions must be concentrated within the predominant rock magma to the smallest possible space so that between them a relatively small amount of magma remains included. The enclosing part of the magma then enters into an exchange with the inclusion, and there is established corrosion, resorption, and recrystallization, though the magma may circulate very slowly between them, *e.g.*, bringing in from without and distributing from within. In consequence of this action the mixed zone supersaturated with material from the inclusion may remain stationary a long time. Under such circumstances a rapid crystallization tending towards a radial structure may set in more readily than in homogeneous granite where the crystallizing conditions naturally must be distributed equally." P. 129.

5. Variolitic specimen from Amtensee, Grythyttau, Orebrö, Sweden (new locality).

A careful petrographic description is given, but the material was insufficient for a study of its genesis.

6. "Pudding granite" from Craftsbury, Vermont.

"This is a biotite-muscovite-granite which contains concretions of biotite that are quite uniform in size and usually about an inch and a half in diameter. They are spherical or spheroidal in form and corrugated on the surface."[1]

Here Chrustschoff considers that the development of the variole falls into the period of the development of the mica in the host and the spheroids appear to be developed through the local increase of a character inherent in the entire mass; in the variole the quartz-feldspar complex is surrounded by a zone of mica broader and thicker than in the homogeneous rock. The whole phenomenon is considered as the result of concretionary action.

7. Feldspathic variole from Aldersbäck, Sweden (new locality).

The sum of the observations indicates that this variole is a resorption residue of a holocrystalline, macrovariolitic rock.

8. Variolitic quartz-diorite from Svartdal, Norway.

Here the ores and apatite balled into a glomero-porphyritic mass served as a center of crystallization so that the rock is "consequently determined as an original macrovariolitic quartz-mica-dioritic, whose spherulitic form of structure is autogenetic and due to the constitution, as well as to the mode of solidification, of the magma." P. 177.

9. Variolitic gabbro from Romsas, Askim, Norway.

The varioles were local developments along the sides of a laccolitic mass and were mechanically disseminated, locally, through the mass. The varioles crystallized under intratelluric conditions and subsequently had formed about them a rim of amphibole.

10. Variolitic amphibole-granite from Slattmossa, Sweden.[2]

Here the core is more basic than the mother rock, and we thus conclude that it is an old basic secretion around which have been formed shells of intermediate acidity. This rock, consequently, is not an original macrovariolite, but is the product of an early secretion of basic material.

The above résumé of the results and conclusions reached shows that macrovariolitic rocks belong genetically to at least four classes:

[1] HAWES, Lithology and Mineralogy of New Hampshire, Vol. II., Part IV., p. 203.

[2] HOLST, Geol. Foren., Stockholm, Forhandlung, Bd. VII., p. 135.

1) Those of concentric spheroidal form produced by foreign inclusions.
2) Those where the varioles were formed by the partial resorption of fragments of the locally solidified magma.
3) The so-called "pudding granites," due to a concretionary action.
4) Those varioles which are primary structural forms of the magma, or are due to endomorphic contact action.

The *conditions* requisite for the formation of varioles are:

1) A difference in the basicity within the magma.
2) The cores must be near each other.
3) There must be a difference in temperature between the core and the magma.
4) The temperature must be high enough to aid resorption but not sufficient to permit the complete resorption of the fragments.

While the work is occupied primarily with a study of the origin of macrovariolitic rocks, it is full of incidental studies of the minerals encountered. This is especially true of zircon, the feldspars, and perthitic intergrowths, while there are many suggestive points on phenomena frequently seen in quartz, apatite, hornblende, etc. On the whole the work is an example of a careful, exhaustive study of a circumscribed problem.

EDWARD B. MATHEWS.

On the Banded Structure of Some Tertiary Gabbros in the Isle of Skye. By SIR ARCHIBALD GEIKIE and J. J. H. TEALL. Quart. Jour. Geol. Soc., November, 1894. Vol. I., pp, 645–659. Pls. XXVI., XXVII., XXVIII.

THE importance of this study of the Tertiary gabbros of Skye is twofold, as pointed out by the author: First, as a contribution to our knowledge of the structures which may be assumed by igneous rocks at the time of their solidification, or prior to their consolidation. Second, as an aid to the elucidation of some of the most perplexing problems in the study of the crystalline schists.

The rocks described are part of the volcanic complex which forms the picturesque group of mountains known as the Cuillin Hills in the southern portion of the Isle of Skye — a vast aggregation of indurated tuffs, agglomerates, lava-flows, besides intruded bodies that have broken

through the earlier accumulations, and have been exposed to view by subsequent erosion.

The gabbros in question are among the more recent rocks, though not the latest, and exhibit no trace of crushing, recrystallization or other signs of metamorphism. They appear to have remained in the condition in which they originally crystallized. Moreover, no great terrestrial disturbance has affected the region since the time of their eruption. They are said to form sheets or sills varying from a few feet to many yards in thickness, each band consisting of many parallel layers of lighter and darker material, which correspond to the trend of the sheet itself. The component layers vary in thickness from mere paste-board-like laminæ to beds a yard or more in thickness. They are sometimes as parallel and regular as sedimentary deposits. But, traced along the strike, they are apt to vary in thickness and even to die out. Their appearance is quite like the banding of gneisses.

The microscopical study of these rocks shows their mineral constituents to be like those of normal olivine-gabbros, and the differences between the light and dark bands to be due to differences in the relative proportions of the minerals.

The crystallization of the mass is continuous across the bands, the individual crystals interlocking in such a manner as to make it evident that all crystallized from a molten magma at approximately one time. The white bands in some cases consist almost entirely of labradorite, while the extreme dark bands are made up of augite and titaniferous magnetite.

The cause of these differences in composition of alternate layers of gabbro is considered to be a differentiation of the magma previous to its intrusion among the rocks in which it consolidated. The banding is the result of the intrusion of a heterogeneous magma. The original shapes of the more or less differentiated masses that composed this heterogeneous magma are not known, their intrusion through fissures would produce a laminated arrangement.

A comparison of these rocks with certain ancient gneisses is drawn, especially with the anorthosite rocks of Canada, and with certain ultra-basic portions of the Lewisian gneiss of Scotland; the similarity in their structures is pointed out, and a correspondence in their origin is suggested.

The analogy between the banding in both these kinds of rocks strengthens the view now generally held by geologists, that the older

gneisses are mainly rocks of igneous origin. While recognizing the undoubted evidence of secondary dynamic action in many regions, and the absence at present of criteria by which original and secondary structures may be discriminated, the authors are strongly of the opinion that much of the banding of gneisses, as distinguished from mere foliation, may be an original structure due to the conditions in which the igneous magma was erupted and consolidated.

The necessity of establishing the prevalence of such differentiated lamination in basic rocks, and of recognizing its occurrence to any considerable extent in granitic masses, is self-evident after the bearing of such facts on the nature and origin of the ancient gneisses has been so clearly set forth.

JOSEPH P. IDDINGS.

Preliminary Report on the Geology of South Dakota. By J. E. TODD, State Geologist. (South Dakota Geol. Surv., Bul. No. 1, 172 pp., 5 plates, Prelim. Geol. Map. Sioux Falls, 1895).

Summaries of the progress up to date along a particular line of work, or of the knowledge of the geology of particular regions are always welcome. This is particularly true when the report covers a region of so wide and varied interest as South Dakota and one the literature of which is so badly scattered. Since the early work of Hayden in the eastern and of Newton and Jenny in the western half of the state the papers on the geology of South Dakota which have appeared have been fragmentary only. They have, however, modified our ideas of the geology of the region in many important regards. As a foundation for the future work of the Geological Survey Todd has brought together in convenient form all this mass of information and has added to it, as a result of his several years work in the region, a great deal that is now for the first time published.

Among the new points which may be noticed are, the recognition of the Silurian as present in the Deadwood section and the pointing out of the beds which must represent the Devonian if it be at all present. A number of caves in the Carboniferous are described in detail. In one of them, Wind cave, is a curious calcite formation called "box-work." The peculiar dome-like surface of the Purple Limestone, it is suggested, may be due to the leaching out of salt beds of irregular thickness below. The marine origin of the Dakota is

argued for, the material of which it is composed being supposed to have been derived from the Sioux quartzite or possibly the Carboniferous of the Mississippi Valley. The author follows King in grouping the Benton, Niobrara and Pierre as Colorado and does not recognize the Montana, the Fox Hills being mapped alone as the Fox Hills Group. In the present state of knowledge this is undoubtedly almost a necessity so far as mapping the area is concerned, but it is to be hoped that more detailed studies will allow the divisions now so generally recognized elsewhere to be differentiated. The White River beds are described in detail, especially interesting notes on the presence in them of sand-dikes being given. At the Bijou Hills a fine-grained quartzite of greenish tinge is noted in the Loup Fork beds. Certain obscure beds of sand and clay in the eastern part of the state and in part in Iowa are somewhat doubtfully referred to latest Pliocene or earliest Pleistocene time and are considered as possible lacustrine beds contemporaneous in age with Lake Cheyenne.

Four moraines are traced: the First or Altamont, Second or Gary, Third, and Fourth. On the map these are not marked, the limit of drift alone being shown. The drift found in the Black Hills region is considered to be "a kind of delta deposit formed by streams shifting to and fro upon a plain of deposition." Some very interesting facts regarding river terraces which may clear up some of the doubt regarding the early history of the rivers in the region are given.

In a résumé of the geological history of the region it is pointed out that the eastern half of the State was dry land during Palæozoic time, and from this it is argued that the condition for the formation of coal existed during the Carboniferous and that mineral may, perhaps, be found to occur in the middle of the State. In the chapter on economic geology the various minerals, building stones, artesian wells, and other similar topics are briefly discussed.

The report contains the usual number, or perhaps more than the usual number, of typographical errors; fortunately, however, very few confuse the meaning. It is an exceedingly compact and valuable compendium of the geology of this comparatively unknown but very rich geological province.

H. F. Bain.

The Geomorphogeny of the Coast of Northern California. By ANDREW C. LAWSON. (Bulletin Geological Department of the University of California, Vol. I., No. 8, November, 1894).

This paper gives the results of Professor Lawson's study of the coast north of San Francisco. It is a continuation of the study south of that point as published in No. 4 of the above publication. The topography of the northern coast of California is that of a dissected table-land sloping from an altitude of 1600 feet on the coast to 2100 feet farther east. In the vicinity of Eel River this plain truncates the edges of a sharp syncline of Pliocene beds, having a thickness of more than a mile.

The axis of the syncline is normal to the coast. Of the 36 species represented by fossils only 14 are extinct, while 18 are not known in the Miocene. Along the coast are numerous well-developed ocean terraces at various levels up to the top of the table-land. The streams are more precipitous in their lower than in their middle courses. The Eel River, owing to the softness of the Pliocene beds — the Wild-Cat series — has a broad flood-plain in contrast to the gorges of the other streams formed in the hard Mesozoic sandstone. In the vicinity of San Francisco the channels cutting across the lower terraces are sunken, giving a fjord-like character to the region and forming the Golden Gate and Bay of San Francisco.

The history of the region described is read by the author as follows: (1) The formation of a great coastal peneplain in Pliocene times accompanied by the accumulation of marine sediments. To this period belongs the deposition of the Wild-Cat series which took place *pari passu* with the sinking of that area. (2) The orogenic deformation of parts of this plain and folding of Pliocene beds without changing the general altitude of the peneplain. (3) The reduction of upturned Pliocene beds to baselevel and the limited extension of the peneplain between uplifted blocks of other areas. (4) The progressive uplift of this peneplain to an altitude of 1600 to 2100 feet, the adjacent mountains being influenced by the same elevation. The stages of this uplift were marked by the coastal terraces, but the halts were, in general, too short to produce stream terraces by side shifting. (5) The erosion of the uplifted peneplain to the present stage of late adolescence or early maturity. In this erosion, structure and relative hard-

ness have been all-controlling. (6) A very recent sag of 100 miles of the coast at the Golden Gate, forming a syncline, the axis of which is probably parallel to the coast. This subsidence is about 378 feet at its maximum point.
A. R. W.

Geological Survey of Alabama. EUGENE ALLEN SMITH, State Geologist. Geological Map of Alabama with Explanatory Chart. 1894.

The map is on a scale of ten miles to an inch, the base being compiled from the records of the United States Land Office, and free use having been made of the atlas sheets of the United States Geological Survey. As shown by the map many of the formations from the pre-Cambrian crystallines to the Pleistocene alluvial deposits are found in the state. There are the Chilhowee sandstones and the Knox shales and sandstones of the Cambrian, three members of the Silurian, one of the Devonian, the sub-Carboniferous and the Coal Measures, four subdivisions of the Cretaceous, four of the Eocene, the Lower and Upper Miocene, the Pliocene (Lafayette) and the Pleistocene.

The map is accompanied by an explanatory chart which is very valuable in presenting in a concise and tabulated form the important facts concerning each of these formations. In the first column are given the names, synonyms, classification and common fossils of each of the formations represented on the map. Another column gives the thickness, the lithological and topographical characters, the area and the distribution. In a third column are placed the useful products found in each formation. The respective soils, characteristic timber growth and agricultural features are briefly given, and also references to the reports in which the formations are more fully described. Some such scheme as this, modified as the exigencies of the case might require, would add greatly to the value of all general geological maps.
H. B. K.

Some Coal Measure Sections near Peytona, West Virginia (with two large maps). By BENJAMIN SMITH LYMAN. (Proceedings American Philosophical Society, Vol. XXXIII., November 2, 1894, pp. 282–309.)

This paper contains the results of two preliminary surveys made in 1872, near Peytona, Boone county, West Virginia. The tracts covered by these surveys lie, the one twenty-two miles south of Charlestown, the

state capital, and the other near Brownstown on the Kanawha about ten miles above Charlestown. The peculiar topography, *i. e.*, flat, table-like hilltops here and there, flat valleys, and many cliffs on the almost uniformly abrupt hillsides, is due to the level bedding of a great thickness of rocks at a sufficient height above sea-level. In the Peytona tract the beds dip 51¾ feet to the mile, southeasterly, with slight local variations which cause "swamps" in the mines. On the Parker tracts the dip is slight.

The general section of the rocks exposed in both tracts is given in detail. Of a total thickness of 800 feet in the Peytona tract there are thirteen coal seams with a total thickness of twenty-two and a quarter feet. There are also several very thin seams of iron ore. In the Parker tract the total thickness is 640 feet, and eight coal beds with a total thickness of twenty-one feet. For purposes of comparison Professor Stevenson's general table of the section of Carboniferous rocks for the northern edge of West Virginia is given, and many of the coal seams of these tracts are correlated with important seams in Pennsylvania and northern West Virginia.

H. B. K.

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—GRESLEY, W. S., F.G.S., The "Slate Binders" of the "Pittsburg" Coal Bed, 10 pp.—Am. Geologist, Vol. XIV., December, 1894.

—MEAD, DANIEL W., The Hydro-Geology of the Upper Mississippi Valley and of Some of the Adjoining Territory, 58 pp. and 11 maps.—Jour. of the Assoc. of Eng. Socs., Vol. XIII., No. 7, July, 1894.

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NOTES.

THE Wisconsin Academy of Science, Arts and Letters is making a systematic and vigorous effort to establish a geological and natural history survey of the state. A strong statement of the need of such survey to extend the work of the last one, which was closed about fifteen years ago, has been printed and widely distributed, and the importance of the subject personally brought to the attention of educators, leading citizens and members of the legislature. A bill has been drawn carrying an annual appropriation of $15,000 to be expended under the direction of a wisely constituted commission. The plan for the proposed survey is broad and comprehensive, and yet confined to legitimate and practical lines of investigation. It is to be hoped that the effort will be successful.

AT the recent meeting at the Academy, Professor C. R. Van Hise read a paper on "The Relation of Bedding to Secondary Structures of Rocks," and Professor G. E. Culver discussed "The Abrasive Action of Ice."

A MOVEMENT is being made to secure the establishment of a geological survey of the state of Washington, and an appropriation will be sought from the legislature for that purpose. It is proposed, we understand, to connect the survey with a mining department of the state university, to be simultaneously established.

A VERY commendable effort is being made by Director Walcott of the U. S. Geological Survey, supported by Prof. Harris, U. S. Commissioner of Education, to secure provision for the printing and distribution, to the higher schools of the country, of a set of ten topographic atlas sheets, selected so as to represent types of surface configuration. The distribution is to embrace Grammar, High and Normal Schools, Academies, Colleges and Universities. The maps, it is claimed, can be printed at a cost not exceeding 2.06 cents per sheet. It is estimated that there are about 15,000 schools of the grade that would be entitled to the maps, and that the total cost including distribution would be $5,000, or one-third of a dollar per school. There has already been a considerable demand on the part of teachers for the topographic sheets, and during the past year 300 sets have been distributed in response to such requests, but present provisions are inadequate to a general distribution. With the rejuvenation of the study of geography which is taking place under the influence of modern methods in surface geology, the use of such maps will be very great, indeed they will become indispensable. There should be no hesitancy on the part of Congress in making the desired provision.

DR. A. R. C. SELWYN, after a long term of service as director of the Geological Survey of Canada, marked by large and important results, has retired from its administration and will, we understand, spend some years abroad. Dr. G. M. Dawson succeeds to the directorship.

THE

JOURNAL OF GEOLOGY

FEBRUARY-MARCH, 1895.

SEDIMENTARY MEASUREMENT OF CRETACEOUS TIME.[1]

It is the purpose of this paper to describe certain regular alternations of strata observed in Colorado, to correlate these with an astronomic cycle of known period, and to deduce from this correlation an estimate in years of a portion of Cretaceous time.

Along the base of the Rocky Mountains, and eastward for many miles, the basin of the Arkansas river is occupied by Cretaceous rocks. At bottom are the Dakota sandstones, several hundred feet in thickness; and above these a great body of shales, constituting the Benton, Niobrara and Pierre groups and having a total thickness of 3900 feet. In the main these shales are argillaceous; but at a few horizons they are calcareous, and at one level a sandstone appears, accompanied by a few feet of arenaceous shale. The sandy passage is best developed near the mountains, and disappears altogether toward the east. The calcareous passages are more persistent and have been recognized throughout the district. At least two of them occur many miles farther to the north. As the shales and the associated limestones approach the mountains they do not assume the character of littoral deposits, but remain practically unchanged; and it is thence inferred that the sea in which they were deposited extended to a remote western shore.

[1] Read before the Geological Society of America, December 28, 1894.

The calcareous passages are four in number, and each exhibits a rhythm of sedimentation. The lowest occurs 210 feet above the base of the Benton group, and exhibits an alternation of thin limestone beds with somewhat thicker beds of shale, the shale being more calcareous than the general mass. Each limestone is a few inches in thickness, and the intervening shales are from one to two and one-half feet thick. The average thickness of a pair of beds, including a limestone layer and a shale layer, is eighteen inches, and the number of such repetitions is about fifteen.

Next above are 230 feet of shale, and upon these rest about fifty feet of limestone, constituting the basal member of the Niobrara group. These limestones alternate in an equally regular manner with shales, the layers of limestone being homogeneous and massive, and varying in thickness from one foot to two feet, with three feet as a rare and local maximum. The parting shales range from one to four inches in thickness, and are sharply separated from the limestone. The average thickness of the rhythmic couple, limestone and shale, is as before, eighteen inches.

The third calcareous series, also of Niobrara age, lies ninety feet above the second, the interval being occupied by shale. Through a thickness of thirty feet calcareous shales alternate with those which are less calcareous, and the amount of calcareous matter increases upward, culminating at the top of the series in two beds of chalky limestone. The average rhythmic interval here is between two and one-half and three feet, and the differences in rock texture are of such character as to give a ribbed appearance to the series where exposed on a cliff face.

The fourth calcareous passage is at the top of the Niobrara group, and is separated from the third by 475 feet of shale. It includes several calcareous layers, of which one might be classed as an impure limestone. The rhythmic tendency is clearly manifested, but the number of repetitions is small.

The Pierre shales, overlying these, have a thickness of about 2800 feet.

From these data it appears that, in addition to a secular and

apparently irregular recurrence of physical conditions leading to the disposition of calcareous matter in this district, there was a relatively rapid and remarkably regular alternation of conditions determining the deposition of alternately more and less calcareous matter. The regularity of this minor alternation suggested the possibility that its cause might be discovered, for of the various causes known or supposed to modify sedimentation those which recur with uniform rhythm are comparatively rare. So far as we have definite evidence, the purely terrestrial causes, such, for example, as upheaval and subsidence, the shifting of waterways or divides, and the removal of oceanic barriers, are of irregular sequence; but certain astronomic causes are comparatively regular.

There are many astronomic cycles, and their periods vary widely in extent, but there are only a few to which it is reasonable to appeal for explanation of a rhythm in sedimentation. There are, in fact, but three to which geologists have made such appeal, and my own inquiry has discovered no others. I refer to the period of the earth's revolution about the sun, the precessional period, and the variation of the eccentricity of the earth's orbit. Each of these is known or supposed to have an influence on climates, and the nature of sedimentation may in various ways be influenced by climate.

The period of the earth's revolution does not seem applicable to the sedimentary rhythm under consideration, because a year is too short a time for the accumulation of the sediment. Doubtless eighteen inches of sediment are often added in a year to the sea bottom near the mouths of rivers; but when we consider that many centuries are required to degrade the land to an average depth of eighteen inches, that areas of marine sedimentation are in a broad way commensurate with those of terrestrial degradation, and that the Cretaceous sediments under consideration were accumulated scores and perhaps hundreds of miles from the land, we cannot for a moment imagine that they were deposited at so rapid a rate.

The variation of the eccentricity of the earth's orbit has a

somewhat regular period of about 91,000 years, but the successive maxima are of so unequal values that they cannot well be correlated with the relatively uniform cycles of deposition.

The precession of the equinoxes seems better qualified to explain the Colorado phenomena. As the earth's axis slowly describes its circle on the celestial sphere the relation of the seasons to perihelion is steadily shifted, so that the winter of the northern hemisphere, for example, occurs during one epoch when the earth is nearest the sun, and during another when it is farthest away. The terrestrial consequences of this cycle of change have been discussed by Adhémar, Herschel, Croll, Murphy, Pilar Hill, McGee, Penck, Ramsay, Wallace, Woeikof, Blytt, Ball, Becker and others, and, though there is wide difference of opinion as to the character and amount of the climatic variations which may thus be brought about, these writers are in substantial agreement that the distribution of climates may be materially affected. The precessional period is about 26,000 years, but the position of perihelion also moves—for the most part in a direction opposite to that of the equinoxes—and the resultant of the two motions has an average period of about 21,000 years. It is not absolutely regular, but ranges ordinarily within 10 per cent. of its mean value, and exceptionally to 50 per cent. above and below.

I shall make no attempt to determine what were the climatic oscillations affecting Cretaceous sedimentation in Colorado nor how their influence was exerted. For the purposes of the present discussion it seems sufficient to point out that the local character of sedimentation might be influenced by changes in the local distribution of terrestrial climates:

1. A periodic change in the circulation of the winds might modify the currents of the Cretaceous sea in such way as to bring to this district at one time argillaceous material and at another time calcareous material.

2. A general change of climate producing glaciation about the two poles in alternation, as inferred by Croll and others, might shift the center of gravity of the earth in such way as to

make the sea alternately advance against and recede from a coast. Even a small oscillation of this sort might render the principal load transported by streams from a coastal plain alternately chemical and fragmental; and a great oscillation, by causing the coast line to migrate, might periodically revolutionize the distribution of sediments in the sea.

3. If the climate of a broad peneplain were by precession made alternately moist and dry, then during moist epochs it would be densely clothed with vegetation, subterranean waters would be highly charged with organic acids so as to dissolve much lime carbonate, and mechanical degradation would be impeded by the vegetal mat. During dry epochs vegetation would be sparse, water would have little power of solution, and relatively rapid mechanical degradation would cause the residual clays to be transported to the ocean.

Adopting 21,000 years as the time unit corresponding to each sedimentary alternation in the calciferous portions of the great shale bed, it remains to estimate the rate of deposition of the more argillaceous portions. As already stated, the sedimentary cycle repeats itself every eighteen inches where the principal deposit is limestone; it also repeats itself every eighteen inches where the limestone makes but one-fourth of the total deposit; and it repeats itself in about 2.7 feet where the calcareous material suffices only to modify an otherwise argillaceous shale. It would appear, then, that the shale was on the whole deposited more rapidly than the limestone, so that in the great bodies of shale something more than 2.7 feet of sedimentation should be correlated with a unit of the time scale. It is moreover true that certain portions of the shale are of different type from those associated with the limestone. This difference does not find definite expression in the chemical composition but appeals to the eye. All shales near the calcareous passages are pale gray in color, while there are important beds in the upper and lower portions of the Benton series and in the upper part of the Pierre series which are dark gray. These constitute about one-tenth of the entire series. It is not clear whether we should ascribe

a relatively rapid or a relatively slow deposition to the dark shales, but the fact that the shale body is not entirely uniform in character tends to increase the probable error of an estimate of its rate of deposition. It appears to me that an allowance of four feet of local sedimentation for each astronomic cycle should afford a somewhat conservative estimate for the corresponding portion of geologic time. Upon this basis the 3900 feet of sedimentation required about twenty million years, and this estimate covers the Benton, Niobrara and Pierre epochs. These epochs constitute a part of the Cretaceous period, being preceded in the chronology of the Great Plains province by the Dakota and Comanche epochs and followed by the Fox Hills and Laramie. As the sediments representing those epochs are of different character from the shale to which computation is here applied, the estimate cannot be extended to cover the entire Cretaceous period without materially increasing its probable error.

The reasoning here employed is strictly parallel and partly identical with that of Blytt in his discussion of "The Probable Cause of the Displacement of Beach Lines" (Christiania, 1889). It differs most conspicuously in the interpretation of the influences of dry and moist climates. He correlates fragmental sediments with warmth and moisture, and chemical with coolness and dryness. In discussing the Cenozoic sedimentation of various European countries he finds the alternation of clay and lime carbonate to have an average thickness of 51 inches, nearly three times that observed in the Cretaceous of Colorado.

On the authority of Geelmuyden, Blytt states that the precession period should theoretically have been relatively short in earlier geologic eras because then the axial rotation was more rapid and the oblateness of the spheroid greater; and to whatever extent this was true in Cretaceous time the preceding estimate of twenty million years should be diminished.

That the logic of this discussion may be quite clear, some of its leading points are briefly restated. Certain parts of a shale body are found to exhibit a rhythm of sedimentation, the cycles of

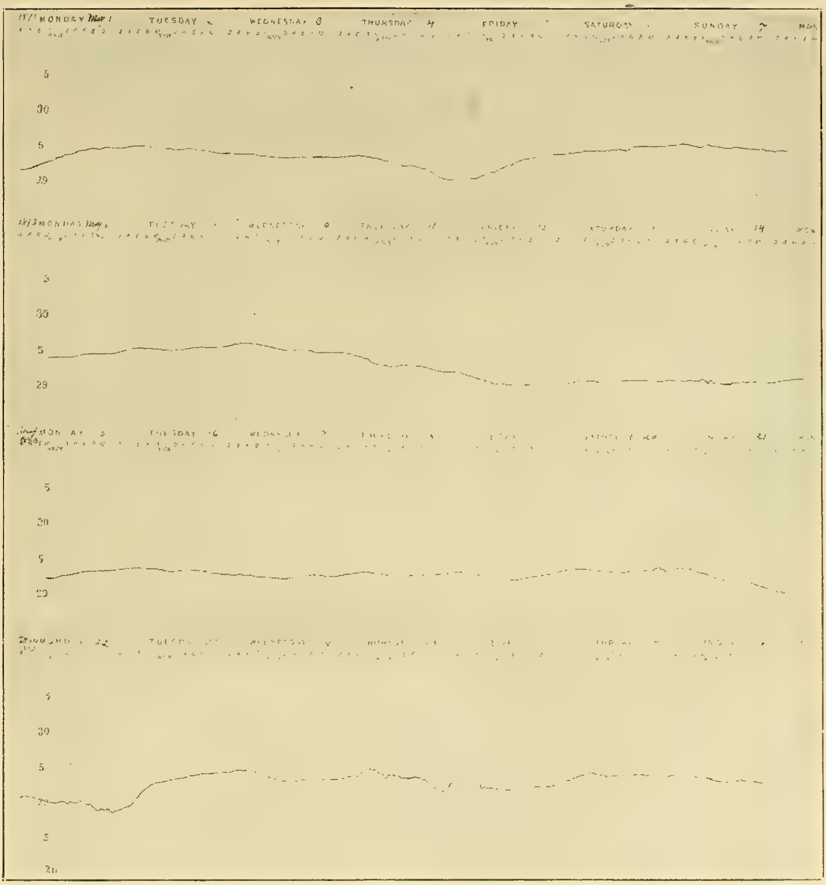
deposition being repeated in from eighteen to thirty-three inches. After making certain allowances, the average unit of deposition for the whole body of shale is assumed to be four feet. From the regularity of the sedimentary rhythm and the large number of its cycles, it is assumed to have been occasioned by a regular rhythm of conditions. The cycle of deposition is correlated with the precession-perihelion cycle — because this alone, of the various cycles known to the writer, appears competent to explain the phenomena. In discussing its competence, the ability of the precessional cycle to produce climatic oscillations is postulated without argument (because it has already been treated at great length by others), and ways are suggested in which climatic oscillations might result in the observed cycle of sedimentation. Assuming that the general inference is valid, the specific estimate is qualified chiefly by the uncertainty in passing from those portions of the sedimentary column where rhythm finds expression in the alternate abundance and scarcity of lime carbonate to the other and greater portions of the column from which lime carbonate is nearly absent. This uncertainty is believed to be represented by the number 2 as a factor of safety; that is, the true period may be either twice or only one-half the estimated period of twenty million years.

G. K. Gilbert.

USE OF THE ANEROID BAROMETER IN GEOLOGICAL SURVEYING.

An attempt to unravel the geologic structure of any area should always be preceded by the establishment of a datum plane, and the reference of all points in the area to it, or in other words the geologic, should always be preceded by a topographic survey. This I take to be axiomatic, yet in practice such a preliminary survey is seldom made, except by the larger organizations, which are under state or national patronage, and not always even by these, because of the great expense involved, and because very few geologists are sufficiently familiar with the instruments and methods of the engineer to undertake such a work, and are not in a position to employ an engineer to do it for them. In reality however, results sufficiently accurate for practical purposes may be reached with an expenditure of time and money almost nominal, and by a method which should be mastered by every field geologist, whether he expects to make such surveys or not, on account of the use he can make of it in other directions. It is the object of this paper to set forth a method which I have used successfully for this purpose.

The aneroid barometer is essentially a metallic box having one or both ends formed by a thin elastic plate, which is usually corrugated to increase its elasticity, and the ends are often connected by a delicate spiral spring with the same object in view. If the air is partially exhausted from such a box, the elastic diaphragms will be forced slightly inward, and in this condition will respond to the least change in weight of the air. The small motion thus engendered is rendered visible by a system of three levers, the long arm of the last being connected by a chain with an axis carrying an index, which revolves in front of a graduated arc. The graduated circle is usually double, the inner arc indicating the weight of the air column in inches of mercury, while



BAROGRAM FOR MAY, 1893.

the outer shows corresponding differences of elevation in feet; for greater accuracy in reading, a vernier is usually attached. Instruments of this kind are to be had, which will plainly indicate differences of one or two feet in elevation. It is of course understood that these readings represent relative elevations only.

Equipped with an accurate land-survey map and an aneroid, the detailing of the topography of an area would be a simple matter, if it were not for the numerous sources of error which inhere in all barometers, but more especially in the aneroids. These sources of error may be classified as mechanical, observational, thermal, and atmospheric. They will be discussed in order, and the means of controlling them indicated.

Mechanical sources of error.— However perfect the mechanical construction of an aneroid may be, a slight shifting or cramping of its parts may give rise to an amount of friction which will prevent the registering of small changes in pressure, and when the change becomes sufficiently great to overcome the friction, the index will jump to its proper place. This difficulty may be overcome by gently tapping the face and side of the instrument before eaeh reading. It is to be borne in mind that while a gentle tap will release the mechanism, a more vigorous one is very liable to produce the error we are seeking to avoid.

Another mechanical source of error arises from slight changes which are continually taking place in the elasticity of the diaphragms. To avoid this the aneroid should be tested from time to time on known elevations, and the tension of the diaphragms regulated by a small screw at the back of the instrument, until the elevation is correctly given.

Errors in observation.—The weight of the levers is in part borne by the diaphragms, and must cause movement in them when the position of the instrument is shifted, hence all readings should be taken with the instrument in the same position, preferably with the dial horizontal. This is a matter of great importance, for the reading of a delicate instrument may be changed one hundred feet by simply reversing its position. If, however, the instrument is uniformly read from the same position, the

weight of the levers, etc., bearing on the diaphragms will always be the same, and so this source of error will be eliminated.

The index of a well-made aneroid should be exceedingly fine, flattened vertically, and should revolve as close as possible to the graduated arc, but even when both these conditions are fulfilled the reading may be varied as much as twenty feet by changing the line of sight, hence the instrument should always be held so that the line of sight will be perpendicular to the dial.

Errors due to changes in temperature.—All first-class instruments are supposed to be compensated for changes in temperature, but the compensation is never perfect. Each aneroid should be tested under varying temperatures, and the ratio of error noted. It will generally be found so small that it may be disregarded except in extreme cases, but if the ratio is large the instrument should be rejected.

Errors due to changes in atmospheric pressure.—The atmosphere is filled with eddies, formed by ascending and descending currents, which are called cyclones and anticyclones respectively. These eddies generally originate over the elevated plateaus of the cordilleran system, spread out until their diameter is measured by hundreds of miles, and move in an easterly direction across the continent, with an average velocity of twenty to thirty miles per hour.

In the eddies formed by ascending currents, or cyclones, as the air rises, it is replaced by surface currents which set in from all directions, with a spiral motion, toward the center. A careful study of an area marked "low" on the daily map issued by the National Weather Bureau will make this clear. As the cyclone moves toward some easterly point a wind from that direction tells of its approach, while a change in direction from east, through north or south, to some westerly point tells of its passage.

As soon as the particles of air come within the influence of the eddy, they are drawn upward, at first slowly, then more rapidly, until near the center they acquire the almost vertical motion of the vortex. This upward tendency of the air lessens

its apparent weight, and causes the barometer to fall. *A falling barometer indicates an approaching cyclone.* The fall continues until the trough, or line perpendicular to the direction in which the cyclone is moving, is reached, when it is changed to an upward movement.

This upward impulse of the air particles results in a loss of heat, and condensation of the contained moisture into visible drops, which are blown by the rapid currents of the upper atmosphere into long, wispy, hairy, cirrus clouds, which reach far beyond the cyclone's front. *Gradually thickening cirrus clouds herald a cyclone.* Behind the axis, the outflowing air has to contend against the general motion of the atmosphere, which is from west to east, and hence its velocity is much lessened. Any moisture condensed in this portion of the area will tend to form lumpy cumulus, rather than windy cirrus clouds. *Cumulus clouds mark the rear of the cyclone.*

The intensity of a cyclone, or the velocity of the ascending current, and consequently the rate at which the barometer rises or falls (barometric gradient) depends largely on the supply of moisture. If the amount of moisture carried into the area remains constant, the intensity of the cyclone, and the gradient, will be constant. If it increase, the intensity and gradient will increase, and if it diminishes, both will diminish, or if it fails, both will disappear. If the supply comes equally from all directions, the cyclone will remain nearly or quite stationary, but if the winds from one quarter bring more moisture than those from the others, the cyclone will move in that direction with a velocity governed by the supply. Changes in direction may produce as marked an effect on the gradient as changes in intensity, for they bring the observer into another part of the area. Many illustrations of change in gradient will be found in Plate I, which is the tracing of a self-registering barometer for the month of May, 1893.

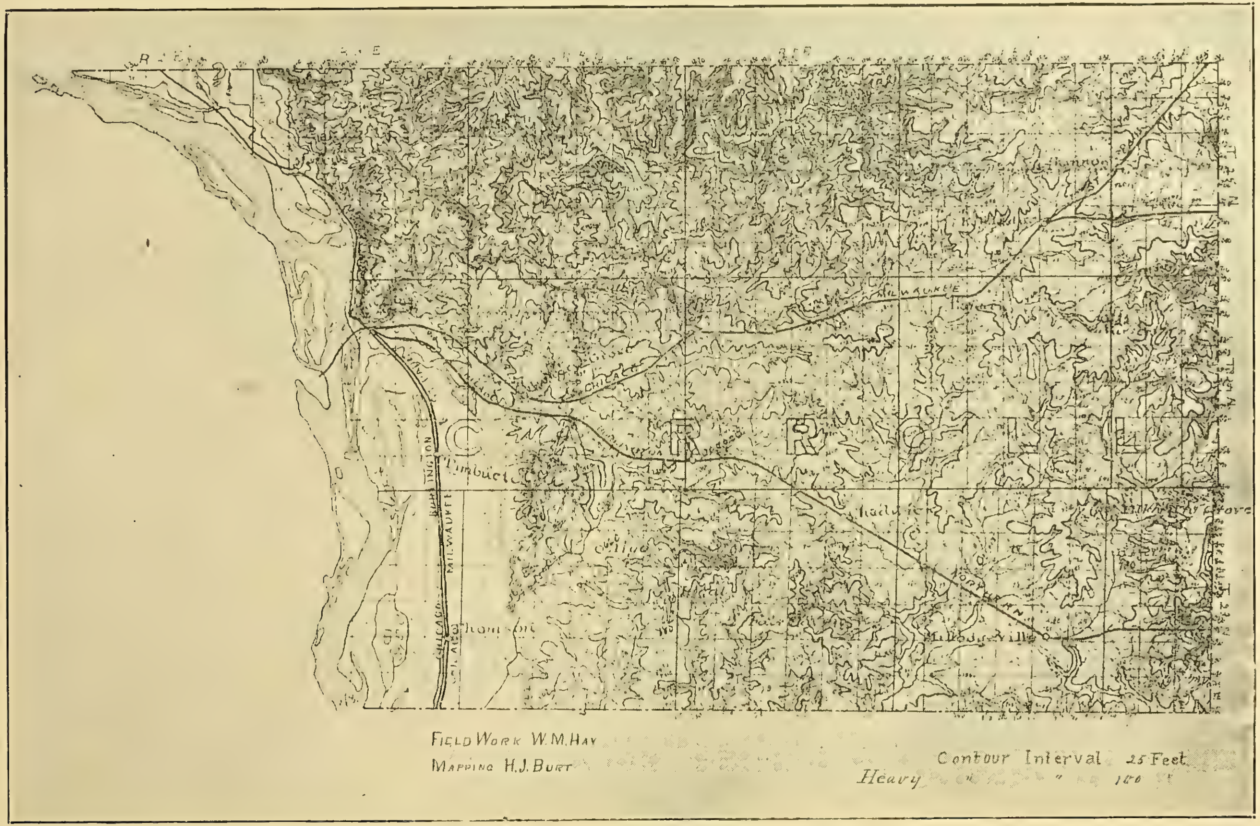
The characteristics of the cyclone which should be remembered in this connection are wind easterly in front, westerly in the rear; gradually thickening cirrus clouds in front, with cumulus

clouds in the rear; barometer falling in front, rising in the rear. It should also be remembered that a change in intensity or direction, may cause the barometer to fall in the cyclone's rear, or rise in its front, and that any change in direction or force of wind, or in character of cloud, is generally accompanied by a change in gradient.

In the descending eddy, or anticyclone, the conditions are just reversed. As the descending air nears the surface of the earth, it slides off horizontally, flowing away from the center in all directions, with a spiral movement; hence as the progressive motion of the anticyclone is from west to east—*a west wind must be its herald and an east wind mark its rear.* As the air from the colder upper regions settles toward the warmer earth there will be little tendency to form clouds, except those of the pure stratus type. In fact this is the only type of cloud which can occur in a typical anticyclone as defined above, but for reasons that will be explained further on, both cumulus and feathery cirrus clouds do occur in most anticyclonic areas. The downward motion of the air increases its apparent weight and so *the barometer rises in its front and falls in its rear.* Anticyclones are also subject to changes in intensity and direction similar to those which occur in cyclonic areas.

The characteristics of the anticyclone are: wind from some westerly point in front, becoming easterly in the rear; generally a clear sky, with perhaps a few cumulus clouds in front, and cirrus in the rear; rarely the whole sky becomes dull and leaden from the formation of pure stratus clouds; barometer rising in front, falling in the rear.

For our present purpose we may assume that the entire atmosphere is made up of such cyclonic and anticyclonic areas, in fact the assumption is not far from the truth in this latitude, and as each floats over us, it causes the index of our barometer to move upward or downward, the extremes covering an arc that represents nearly three thousand feet of elevation. From this it will be seen how fruitful a source of error these atmospheric configurations may be, and how essential it is for anyone who



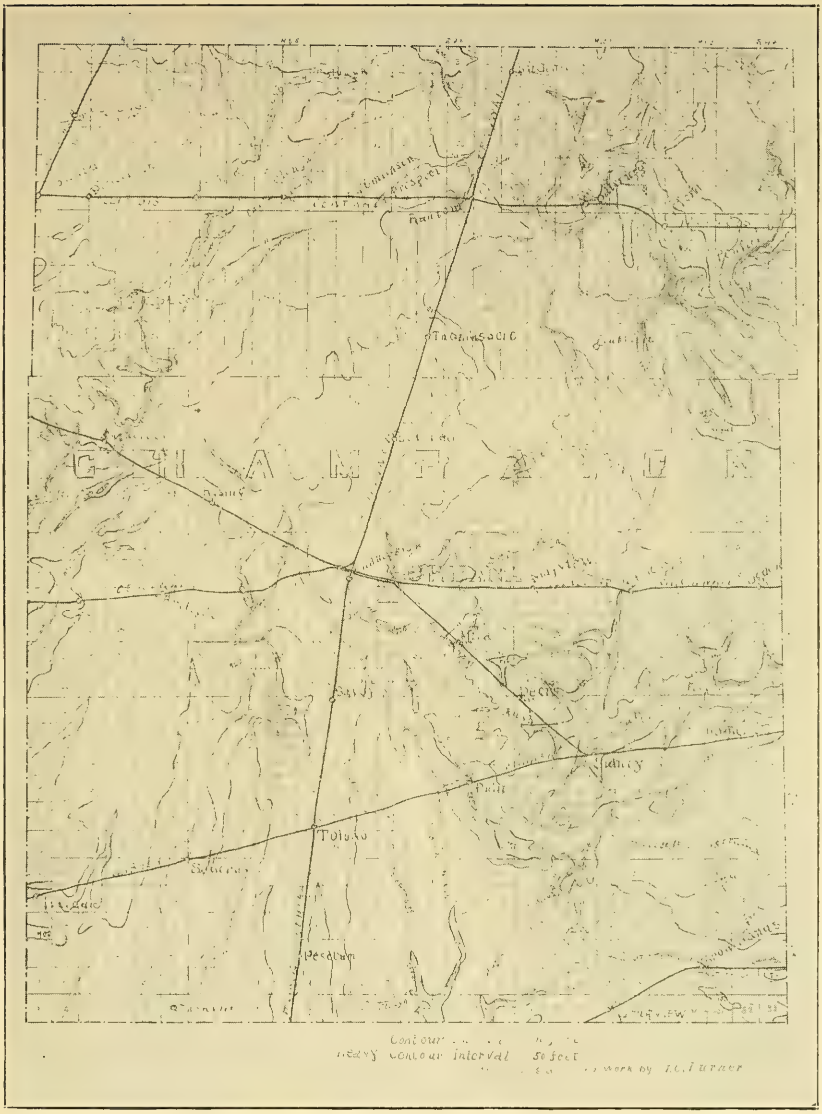
CONTOUR MAP OF CARROLL COUNTY, ILLINOIS.

wishes to use an aneroid for topographic purposes, to make himself thoroughly familiar with all their characteristics. Perhaps there is no better way to do this than to draw across a cyclonic area as delineated on the daily weather map, a line which shall be considered the trace of the observer's position as the area passes over him, and consider carefully the changes in the direction of wind, character of cloud, and barometric pressure that would occur. A series of such lines, some straight, others crooked, will bring out the cyclonic characters better than any amount of description could. For further information on this subject, see "Weather" by Abercrombie, Appleton's Science Series, "Elements of Meteorology" by Davis (Ginn and Company), and "A Popular Treatise on the Winds" by Ferrel, (Wiley and Sons). The last is not nearly so popular (elementary) as its title indicates, but is an excellent work.

From what has preceded, and an inspection of the barogram in Plate I, it is evident that the errors which may arise from changes in atmospheric pressure are very great, and that, if no measures are taken to correct them, the barometer would be entirely useless to the topographer, or even for hypsometry, but it is also evident that the errors so far considered may be corrected in either of two ways. The area to be surveyed may be divided into sections, each covering only a few square miles, and a self-registering barometer, carefully adjusted to read with that which is carried into the field, placed near the center of each section while it is being surveyed. The trace of this instrument will indicate the changes in pressure that have occurred, and furnish data for the correction of the readings taken in the field, provided the time at which each reading is taken is made part of the record. This method is open to the objection that the observer works mechanically and blindly, and is thus unable to apply the many little checks which he would otherwise find so useful, as well as to detect the larger errors, arising from surges, that will be spoken of further on. Another method is that by the use of gradients. Here the observer, before beginning work in the morning, carefully ascertains the barometric gradient, that

is the amount of rise or fall in a fixed interval, and corrects each reading as taken, by adding or subtracting the proper amount. In this way all errors due to pressure may be eliminated, so long as the gradient remains constant, but an inspection of Plate I, or of any barogram, will show that a gradient is not to be trusted for any great length of time. Sometimes it will run along for hours, or even days, with very little change; this is especially true in anticyclonic areas, and again several abrupt changes may occur within a few hours. On this account the observer must not only test his gradient by stopping at intervals to note the rate of change, but he must be continually on the alert for the signs which presage a change, such as variation in the character or amount of cloud, or the direction or velocity of the wind, etc. At first the recognition of those changes which mean a variation in gradient will be difficult, but a little practice will make it almost instinctive. This method has the advantage that it requires the wide-awake, intelligent judgment of the observer all the time he is in the field, and, when combined with careful descriptions and sketches made from all prominent points, yields very creditable results. If only one method for the correction of these errors can be used, this is decidedly the better, both for the reason indicated, and because there are times when the barometric variation is not the same over even so small an area as that indicated. It is desirable however, where possible, to combine the two, using the first only as a general check on the second.

In spite of all precautions, however, it will be found that there are times when the barometer is worse than useless. Such a time is indicated on Plate I, beginning at 9 in the morning of the 25th and ending shortly after noon on the 26th, another beginning at 3 in the afternoon of the 22d and ending at 4 in the morning of the 23d. Short disturbances of this kind occur also at 2 A.M. of the 21st, and shortly after noon of the 14th. These irregular movements almost always occur during storm periods accompanied by gusty winds, and are generally of short duration, though I have known them to extend over the greater part of a week.



CONTOUR MAP OF CHAMPAIGN COUNTY, ILLINOIS.

At such times the observer should proceed with great caution, or what is far better, cease work entirely.

An explanation of these irregularities may be found in the fact that cyclones and anticyclones are not the simple eddies that they are commonly supposed to be, but contain within them many smaller ones, each with the characteristics of the larger, but which pass over us so swiftly, or are so shallow, that they escape notice. It is these small eddies that give rise to the cumulus clouds and cirrus stripes of the anticyclone and to the cirrus stripes and clear spaces of the cyclone, while to the larger ones, or groups of them, we owe our thunder storms, and tornadoes. They are technically known as surges.

Having shown that by the exercise of the same intelligent attention which must accompany any scientific work, the sources of error which inhere in the aneroid may be kept under control, and that results sufficiently accurate for the purpose indicated may be reached, we come next to consider the method of procedure in the field.

Having assumed a datum plane, far enough below the surface at the starting point so that no negative readings need be recorded, we run a series of base lines crossing the area at intervals of five or ten miles, using every precaution to guard against errors, and establishing stations at frequent intervals, so well described that they may be recognized when again met with. These base lines should all be doubled, that is, each should be run in the opposite direction, readings being taken at the stations established during the first traverse. A comparison of the two sets of readings will usually enable the observer to eliminate all errors, if the work has been well done, but if wide differences are still found, a third traverse, more carefully made, should correct them. These base lines will furnish the means of establishing the water slopes of the streams that cross the area, and these, together with the base lines themselves, will enable the observer to frequently check his work while making the traverses with which the details are filled in.

No topographic survey can be absolutely correct, that is, the

results of the very best are only generalizations, taking account of the larger irregularities of surface, but paying no attention to the lesser ones, hence it is necessary that at the outstart a thorough understanding should be had as to the degree of accuracy desired, so that the traverses may be arranged to touch all points of elevation or depression that come within these limits. All points at which observations are made should of course be accurately located on the map. Much use should also be made of descriptions and sketches made on the spot.

Where railroads, or other lines of levels, cross the area, their profiles should be taken as base lines, but too much reliance should not be placed on their accuracy. Some of them are excellent and their results may be taken without question, but others are very poor. An error of one foot to the mile is not at all uncommon in these surveys, and much larger ones are frequently met with. One which I have in mind, the official profile of an Illinois road, has an error of nearly one hundred feet in about fifteen miles.

The results of all observations having been recorded in their proper places on the map, they should be translated into contour lines, which will at once indicate the variations in surface. See Plates II. and III. I would strongly advise that the preliminary contour map be made *by the observer*, and for each small section separately while the details of surface are fresh in his mind. These maps can then be brought together and re-drawn by more expert hands.

It was my fortune during the years 1892–3 to direct a survey of the entire state of Illinois, along the lines indicated above. The time allowed was so short that the work had to be pushed winter and summer, without regard to weather. The task was rendered much easier than it otherwise would have been, by the large number of railroad lines which cross the state in every direction, and by the kindly courtesy of their officials, through whom I was enabled to obtain profiles of the lines. These profiles, after they had been brought into accord, formed admirable base lines from which to carry on the other work. Under these conditions

the task was completed in sixteen months, with an average force of ten men, and at a total cost of twenty-five cents per square mile. The degree of accuracy attained can be inferred by the following facts. Each county was surveyed separately. As a rule the observers who surveyed contiguous counties were unacquainted with each other's results. When the county maps were brought together it was found that the average difference in the elevation assigned to common points was less than ten feet. A difference of twenty-five feet was occasionally met with, but was not frequent. These errors were corrected, and the maps re-drawn, omitting most of the elevations, but retaining the contours. Plate II. is a reproduction on a much reduced scale of the map of one of the rougher counties, while Plate III. represents one of the more level ones.

Better results could, of course, have been reached had it been possible to devote more time to the work.

C. W. Rolfe.

University of Illinois,
December 20, 1894.

A PETROGRAPHICAL SKETCH OF ÆGINA AND METHANA.[1]

PART III.

Segregations.—Before taking up the discussion of the chemical composition of the rocks described in Part II. it will be well to describe a series of segregations (endogenous enclosures) found in them, so that their chemical composition, which is closely related to that of the enclosing rocks, may be discussed at the same time with that of the latter.

A few preliminary words may be allowed on the use of the term above given. The various forms of foreign matter that occur in rocks and minerals are of such common occurrence and so frequently referred to that the use of simple terms to denote the different occurrences seems advisable. Those suggested by Lacroix[2] seem to be the best possible, as well as consistent with the present usage of many petrographers. The term *inclusion* (Fr. *inclusion*) is reserved for foreign bodies in the component minerals of a rock which are derived from the same magma as the including mineral; *enclosure* (Fr. *enclave*) denotes fragments of foreign rock in eruptives, *e.g.*, such as have been torn away from the conduit walls; finally, *segregation* (Fr. *ségrégation*, Germ.

NOTE.—As the writer was unable to revise the proofs some errors have crept into the foregoing parts of this paper, and the following corrections must be made:

II. 789, line 18; 806, lines 29, 31; 807, line 17; III. 44, line 3, for "Kolautziki" *read* "Kolantziki."

II. 805, line 7, for "227–239 B.C." *read* "276–239 B.C."

II. 812, line 27, for "von Lubach" *read* "von Seebach."

III. 38, line 31, after "coast" *insert* "of Methana."

III. 40, lines 7, 32, for "Vesili" *read* "Vasili." H. S. W.

[1] Continued from page 46.

[2] A. LACROIX: Sur les enclaves acides des roches volcaniques d'Auvergne. Bull. d. services de la carte geol. de la France. No. 11, 1890, pp. 25–56. Ref. in Neu. Jahrb., 1892, I.,–67.

Ausscheidung) is reserved for the masses (whether isolated or in streaks) formed by the earlier crystallized or solidified portions of the molten magma. The above distinction between "inclusion" and "enclosure" was proposed by me in a paper on the basalts of Kula in 1894;[1] and it will be seen that "enclosure" corresponds to the generally used term "*exogenous* enclosure," while "segregation" answers to the longer "*endogenous* enclosure." The term "segregation" is preferable to "aggregation," "concretion," or "secretion" since the last three are all in general use with well marked connoted meanings.

In almost all the eruptive rocks of the region, with the exceptions of the biotite-dacite of Kolantziki, and the hypersthene-andesites of Oros and Chelona, there are seen spots and patches which differ in color and structure very decidedly from that of the surrounding rock. In the great majority of cases these are irregularly rounded, some, as at Kakoperato and at the hillock in the plain east of Mt. Chelona, roughly spherical or spheroidal, and only in a very few cases subangular. The line of demarkation between them and the surrounding rocks is very sharp, and they vary in size from that of a pea to that of one's head. Since, as will be seen later, these have much the same mineralogical composition as that of the enclosing rock (though differing in structural and chemical characters) they must be regarded as true segregations—the products of an early differentiation and partial solidification of the magma at a presumably great depth, which have been brought to the surface as unmelted remains of still larger masses by the erupted lava stream. Such segregations are not uncommon elsewhere, but the nearest parallel to these here described are those found by Küch[2] in the Colombian andesites and dacites, as well as those in Ecuadorian lavas described by Belowsky,[3] both of whose papers are occasionally referred to.

These segregations are, megascopically, chiefly characterized by a fine, but even, granular structure made up of hornblende and

[1] Am. Jour. Sci. XLVII, 1894, p. 115.

[2] Küch, op. cit. pp, 82–84.

[3] Belowsky, op. cit. pp. 57–60.

plagioclase crystals, and rather dark gray color which on weathering becomes a pinkish brown. Exceptions to this general structure are found in the segregations of the Kaimeni stream, and in one from Mt. Gaiapha, which are much larger grained and look like medium-grained diorites. They carry few phenocrysts though some are seen in almost all the specimens, in most cases of white plagioclase and more rarely of short, black hornblende prisms. The Kaimeni segregations also show several clear, colorless quartz grains with no augite rings, and those from Kakoperato some pinkish quartzes of larger size and surrounded by a narrow ring of green augite.

Under the microscope it is seen that the segregations show in general the same mineral composition as their enclosing rock, except that no quartz was found in the slides, even in those of the dacites rich in quartz. We can distinguish in the sixteen specimens examined two distinct varieties which differ considerably in structural and in mineralogical characters; first with the mineralogical composition of hornblende-augite-andesite, which are found in the rocks of Mts. Pagoni and Gaiapha and presumably also in those of Mt. Chondos, and secondly, hornblende-andesite segregations from the andesite of Kaimeni and the dacites of Anzeiou, Kakoperato and the neighborhood of Kosona.

The first variety has a peculiar porphyritic structure of which the groundmass is not abundant, and is analogous to the mesostasis of some melaphyres. It is quite trachytic in appearance, being composed of colorless plagioclase lathes and leptomorphic grains, with many twinning lamellæ, some of which gave extinction angles of about 15°. No flow structure was noticed, and interstitial glass base seems to be entirely wanting in nearly all the specimens. In this trachytic paste are many small hornblende prisms and needles, all of which are entirely altered to a fine-grained mixture of augite and opacite, and many small, colorless augite crystals either prismatic and broken or of irregular shape, some of which seem to be derived from the large altered hornblende phenocrysts. Magnetite is very rare in these segregations.

The not very abundant plagioclase phenocrysts seem to be identical with those of the surrounding rock, showing twinning lamellæ and carrying the same inclusions, though usually those of glass do not form a distinct "net." One group of large plagioclases includes numerous patches of brown biotite all of which are oriented alike (micropoikilitic structure), and a little biotite also acts as a mesostasis between the plagioclase crystals. The larger augite crystals, which are to be classed as phenocrysts, are quite abundant and do not differ materially from those of the surrounding rock. Some biotite crystals, brown in color and wholly altered, are also seen.

The hornblende which is present in abundance as phenocrysts, though it also bears much resemblance to that of the mother rock, calls for special description. The crystals are all prismatic and, where the original hornblende substance is seen, of the usual brown color, though rather darker in tone. In many of the fresh patches of unaltered hornblende are found narrow bands of much darker color. These bands, which even with the use of the highest powers are irresolvable, show the pleochroism of the regular brown hornblende, though modified by the greater depth of color. In hornblende sections cut normal to the vertical axis they lie parallel to the clinopinacoid, bisecting the obtuse angles of the cleavage lines, while in longitudinal sections (approximately parallel to b(010)) they cut the parallel cleavage lines obliquely in the direction of a positive orthodome. The angle, which is not quite constant, is in general 65°–70°, making the bands lie parallel to the plane f ($\bar{3}01$). These bands are hence seen to represent sections, not of sheets, but of rods, similar to but thicker than those seen in the hornblende of a rock from Mt. Pagoni.

The alteration of the hornblende, however, is its most constant and characteristic feature. The crystals have all undergone a change, so much so that kernels of fresh substance are comparatively rare. In most cases they show a mass, or else a central core, of fine grains of black opacite embedded in a finely granular mass of augite and plagioclase. These occurrences show clearly

that the plagioclase grains are in reality products of the alteration of the hornblende and not particles derived from the groundmass which have penetrated between the augite and opacite grains. In the largest and most altered crystals this opacite core is surrounded by a border or frame of almost pure augite in the form of colorless prismatic grains, giving extinction angles of 36°, and their long axes parallel to the $\acute{c}$ axis of the hornblende, so that the ends of many of these hornblende pseudomorphs have a fringed or bearded appearance. In the less fresh specimens this augite assumes a greenish yellow color, when it resembles more than ever uralitic hornblende. This prismatic augite does not only occupy the border of the hornblende pseudomorphs, but in many cases penetrates the opacitic aggregate in irregular patches. Many of these altered hornblendes show signs of great mechanical disintegration since their alteration, patches and prisms of the secondary augite being seen to have been torn away from their original positions and scattered through the groundmass of the segregation. Küch (pp. 46, 176) observed apparently similar occurrences, though not in segregations, which he refers to a parallel growth of augite and hornblende. This does not seem to be the correct explanation, at least for the present case, and it is most probable that these borders of prismatic augite are due to causes similar to those which produced the opacitic and "augite-opacite aggregate" alterations of hornblende, forming a later and probably the final stage of these.

The occurrence of these alterations in the case of segregations in rocks where they also occur, while they are not found in the segregations in rocks containing fresh green hornblende, is very interesting, and contrary to what Küch and Belowsky observed in their otherwise very similar occurrences. The observation often previously made that only the brown hornblende is liable to this alteration is again confirmed, and this fact seems to be a fundamental one to adopt in any explanation of the set of phenomena. Judging from the present cases it seems certain that the alteration took place before the solidification of the groundmass, which would place the period of alteration of the hornblende

prior to that of the consolidation at a great depth of the magma forming the segregations. This seems at first sight to be at variance with the fact already noted in the case of the hornblende-augite-andesites, that many of the small groundmass crystals are still fresh; so that we seem driven to the conclusion that not only are the conditions under which the alteration may take place extremely variable, but that after hornblende has been formed and altered, a subsequent formation of fresh hornblende may occur. The final stage of the process is similar in physical structure, though chemically and genetically quite different from the final stage of the uralitization of augite, which we know to be due to the action of moisture, and it might be said that instead of hornblende being the stable form of augite, augite is the stable form of hornblende, at least of the basaltic variety.

In one of the segregations of Mt. Pagoni accessory olivine is present in large colorless crystals, of a bright yellow on the edges. While the crystals are of irregular shape they have been formed, as was to have been expected, prior to the formation of the hornblende or augite, both of which are xenomorphic with respect to it. Few of these segregations differ from the type just described. One from Mt. Pagoni seems to have solidified rather more rapidly than the above, as the groundmass is a colorless glass base, hyalopilitic through the presence of numerous plagioclase microlites. In this segregation the bearded hornblende pseudomorphs are especially well shown, and the plagioclase phenocrysts, which are very clear and show few twinning lamellæ, are much more numerous. The other (from Mt. Gaiapha) seems to have been originally very similar, but the groundmass is replaced by colorless calcite, which entirely replaces the glass and acts as mesostasis for the large crystals. Neither the hornblende nor the plagioclase phenocrysts of this segregation nor the surrounding rock in general show signs of decomposition, and it is possible that the calcite is rather a primary than a secondary constituent.

The second variety of segregations differs from those just described in two important respects; the hornblende is green and

the groundmass is vitreous. The groundmass is composed largely of a perfectly clear and colorless glass base, showing no perlitic cracks, in which lie small water-clear plagioclase crystals and skeleton crystals, either forked at each end or forming a hollow square, with some small hornblendes, apatite needles and, in the case of the Methana segregations, some small hypersthene prisms. Round vesicles or gas pores are also not uncommon. In a few cases this base is brownish in streaks and patches, the color being due to the presence of minute brown dust grains, and associated with these (in one specimen) are very many straight black trichites or minute club-shaped microlites often arranged radially. One segregation from Kakoperato, which is especially rich is these brown streaks, contains also many rounded granospherites, which have little or no action on polarized light. These frequently contain, as seen only under the highest powers, extremely small straight black trichites, in fan-shaped aggregates. As in the preceding variety there is no evidence of flow structure either in the groundmass or among the phenocrysts.

The hornblende phenocrysts are in the shape of needle-like crystals or prisms, elongated parallel to $\overset{1}{c}$. When embedded in the groundmass they are automorphic, but are on the other hand generally xenomorphic in respect to the plagioclase, though the converse also occurs. Their color is, it has been said, olive green, and they show no signs of alteration. An exception to this must be noted in the case of one Kaimeni segregation, where they are yellowish brown and generally have an altered border.[1] This specimen shows the dust and black trichites in the groundmass in the greatest perfection, and the small hypersthene prisms are almost entirely altered to a brown or black substance. Large phenocrysts of colorless augite occur in small quantity in one or two of the specimens, but they are rare and call for no special mention except that they are always xenomorphic in respect to the hornblende.

The plagioclase phenocrysts are all automorphic, generally

[1] This enclosure, it must be remarked, is in a scoriaceous lava which shows many signs of decomposition, perhaps due to fumarole action.

giving long rectangular sections, and are mostly perfectly water-clear. They do not show many twinning lamellæ and occasionally have undulatory extinction, but are all certainly plagioclase. The extinction angle of 35° observed in one case indicates that they are anorthite, which is confirmed by the high percentage of CaO found on analysis (cf. Anals. 8, 11, Table I.). A few large stout plagioclase crystals are seen, the megascopic phenocrysts, which resemble those of the surrounding rock. They all show a core of glass network, or of fine plagioclase grains with very little glass, resembling the holocrystalline xenomorphic groundmass of some porphyries. These crystals often enclose flakes of hornblende.

In the reddish hypersthene-andesite of the Methone acropolis are found round, dark gray fine-grained segregations, which on examination under the microscope show no marked difference from the rock surrounding them. They also are hypersthene-andesites, with some accessory brown hornblende phenocrysts and many small hypersthene prisms in the vitreous groundmass, which shows a beautiful flow structure.

It is noteworthy that in all the segregations magnetite, except that due to alteration of the hornblende, exists only sparingly, it being entirely absent in one or two specimens. It is rather more common in those with green hornblende in rather large grains, which are more frequently found as inclusions in the hornblende than in the plagioclase. Zircon, on the contrary, is rather common in all the segregations as small colorless crystals, both included in the other minerals and in the groundmass. These masses show no evident signs of the action of the surrounding molten magma upon them (except in their rounded outlines), and in the enclosing rock itself no traces are to be seen in their immediate vicinity of any change in structure or composition.[1] The presence of glass base in them (also observed by Küch and Belowsky) is interesting and, inasmuch as it is impossible to conceive of the masses having preserved their

[1] For such contact phenomena in the case of enclosures, cf. DANNENBERG, Min. Pet. Mitth. XIV., 1894, pp. 17–94.

individuality and not being completely disintegrated during the violent movement of translation by the lava stream from a presumably great depth to the surface if some solid binding material did not exist between the large component crystals, we must suppose this interstitial matter to have solidified as glass (or trachytic groundmass) at a great depth. This groundmass, whether vitreous or holocrystalline, differs radically from that of the surrounding rock and so cannot be supposed to be due to penetration of the enclosure by the still liquid magma in which it lay. While such enclosed masses have been classed here and by others as endogenous enclosures in the sense already defined (p. 138), yet the presence of such a glass base tends to throw doubt on this view and makes it seem possible that we have here to do with fragments of an earlier lava flow, at present buried deep beneath the later superincumbent lava streams. This question will, however, be discussed at greater length later.

STRUCTURE AND MINERALOGICAL COMPOSITION.

Before we begin the chemical discussion of these rocks it will be as well to speak of one or two points in regard to the general structural and mineralogical characteristics of all the rocks described from this region. As regards structure, it may be said that megascopically the most basic rocks — such as the hypersthene-andesites and from a certain standpoint the segregations — are the most even-grained and show fewest phenocrysts, a porphyritic structure being more and more highly developed, and the size and abundance of the phenocrysts increasing, as a rule, with increasing acidity; the dacites on the whole standing in this respect (as well as chemically) at the opposite end from the Oros hypersthene-andesites. The chief exceptions to this general rule are most of the hornblende-augite-andesites of the Monastery District. To put it broadly, the difference may be expressed by saying that basic rocks are largely groundmass, while the acid rocks are to a much larger extent phenocrystic. Microscopically it is seen also that the groundmass of the dacites, while less abundant, is much

more vitreous than that of the basic andesites. The largely predominating groundmass of the hypersthene-andesites is made up chiefly of plagioclase and hypersthene lathes and augite crystals, with comparatively little interstitial glass base, while in the hornblende-augite-andesites the larger groundmass crystals are fewer in number (though still numerous), and the rather more abundant glass base is very thickly strewn with microlites, magnetite grains and "dust."

In the dacites, on the contrary, and in the more acid andesites, as those of Poros and Spasmeno Vouno, larger crystals are comparatively rare in the groundmass, which is highly vitreous and often typically, though not densely, hyalopilitic with occasional perlitic cracks. The tendency in the basic rocks seems to be toward forming larger crystals in the groundmass, while in the acid rocks the tendency is more toward microlitic development. An excellent illustration of this difference of structure as related to chemical composition is seen in the pyroxene-andesites of Mt. Kouragio and Mt. Chelona, the former containing 54.53 per cent. of SiO_2, while the latter contains 59.83 per cent. The groundmass of the latter is vitreous containing many microlites, but few larger lathes, while in the former the glass base is relatively much less abundant and the number of larger plagioclase and hypersthene lathes and crystals in the groundmass very great.

So that, in general, it may be said that in these rocks the more acid the rock the more vitreous the groundmass, the smaller and more microlitic the crystals in it, and the larger and more abundant the phenocrysts. To this rule there are, of course, exceptions, as seen in the hornblende-augite-andesites, since the chemical composition of the magma is only one of the many factors involved in the crystallization of rocks.[1] But inasmuch as all the rocks of this origin have solidified under quite similar conditions as regards pressure and rate of cooling, they being all massive (domal) eruptions, and stock, dike or sheet

[1] IDDINGS, Crystallization of Igneous Rocks, Bull. Phil. Soc., Washington, 11, 1889, p. 113.

occurrences not being represented, these factors are to a large extent eliminated, and the present occurrences offer a good opportunity for study of the relation of structure to composition. As regards this relation they are quite in accordance with Iddings' conclusion that "the basic magmas exhibit a much greater tendency to crystallize than the highly siliceous or alkaline ones."[1]

But it seems to me that the difference between them is not entirely one of simply greater or less tendency towards crystallization, but that this tendency in the two classes differs in *quality*, and that it is probable that further research will show that the highly acid magmas have a tendency to crystallize about comparatively *few* centers, the result being an eminently porphyritic structure, with a vitreous, felsitic, microlitic or extremely fine-grained holocrystalline groundmass, due probably to the rapid cooling of the still liquid groundmass magma; while in the basic rocks the tendency is to crystallize about very numerous centers, the result being a fine-grained rock with few phenocrysts and the groundmass containing many small crystals and microlites, but comparatively little glass base. It would follow from this that in these last rocks the transition between phenocrystic and groundmass crystals will be much more gradual than in the acid rocks.

Such a relation is clearly shown on comparing the basalts with the trachytes or rhyolites, where the generally porphyritic structure and vitreous or minutely crystalline groundmass of the latter is in striking contrast with the slightly porphyritic structure and groundmass full of small crystals in the former. That the same law probably holds good for the plutonic rocks as well is indicated when we compare the granites and diorites; where, as a rule, the former are much larger grained than the latter, the larger grains being the natural result of fewer centers of crystallization in a magma which was finally completely crystallized.

Such tendencies may be most closely connected with the

[1] IDDINGS, Crystallization of Igneous Rocks, Bull. Phil. Soc., Washington, 11, 1889, p. 107.

greater or less fusibility of the rocks in question, their fusibility being in turn directly dependent on their chemical composition. Lack of space, however, forbids further remarks on this subject, and the examination and elaboration of the suggestion made above must be left for another place.

Mineralogically the rocks of this region do not show, on the whole, very gradual transitions from one species to another, many of the groups being sharply separated from all the others, as in the cases of the hornblende-andesites and hornblende and biotite-dacites. On the other hand there is among the members of the pyroxene-andesite group a gradual transition from the augitic to the hypersthene end, and some other cases occur, as will have been noticed.

The basic rocks are decidedly more pyroxenic than the acid ones, and of the two members of this family present augite shows a decidedly greater fondness for the most basic rocks than the hypersthene, which is one of the main components of a large group of dacites; it will also have been noticed that the hypersthenic andesites are more acid than the augitic. Hornblende is the most prominent ferro-magnesian silicate of the acid rocks, the green being especially characteristic of these, while the brown variety is usually associated with augite. Biotite is not very abundant, but occurs in the most acid rocks, either alone or with hornblende. Magnetite does not show any well defined preferences, but in accordance with the law just enunciated it usually occurs in larger crystals in the more acid rocks.

CHEMICAL COMPOSITION.

The analyses[1] presented in Table I. were made for me by Dr. A. Röhrig of Leipzig, while Dr. H. Lenk of the University of Leipzig had the kindness to make the specific gravity determinations. Care was taken to select the most representative and least altered pieces, though in some cases it was impossible to find quite fresh specimens. The figures in small

[1] TiO_2 was determined as the residue left on volatilization of the silica with hydrofluoric acid. H_2O is the loss on ignition.

TABLE I.

Analyses of Rocks of Ægina and Methana.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
SiO_2	54.86	59.93	55.46	55.87	54.53	59.83	59.94	56.38	61.29	64.06	55.87	64.83	62.90	55.83	67.34	70.81
	0.908	0.992	0.918	0.925	0.903	0.991	0.992	0.933	1.015	1.061	0.925	1.073	1.041	0.924	1.115	
TiO_2	0.05	0.96	0.21	0.01	0.96	0.01	0.02	0.33	0.65	0.18	0.16	0.08	0.18	0.32	0.46	0.07
Al_2O_3	23.08	16.99	16.76	18.74	13.06	17.82	18.40	17.48	17.68	15.25	22.40	17.60	18.29	18.96	15.96	11.82
	0.226	0.166	0.164	0.183	0.131	0.174	0.180	0.171	0.173	0.149	0.219	0.172	0.179	0.186	0.156	
Fe_2O_3	4.41	3.58	5.15	4.88	6.85	3.62	3.69	5.30	6.03	2.72	2.52	4.95	1.79	5.64	3.38	1.82
	0.028	0.022	0.032	0.031	0.043	0.023	0.023	0.033	0.038	0.017	0.016	0.031	0.012	0.035	0.021	
FeO	1.50	1.28	3.00	5.01	4.86	4.60	2.99	2.72	0.30	4.30	1.80	1.82	4.00	3.23	0.80	3.69
	0.021	0.018	0.042	0.089	0.068	0.069	0.042	0.038	0.004	0.059	0.025	0.025	0.056	0.045	0.011	
CaO	6.98	5.92	10.00	8.20	9.83	6.88	6.58	10.89	5.61	3.93	9.20	5.26	5.62	7.40	2.98	4.45
	0.125	0.106	0.179	0.146	0.176	0.123	0.118	0.194	0.102	0.070	0.164	0.094	0.100	0.132	0.053	
MgO	1.29	1.51	2.44	1.39	3.14	1.64	1.95	3.10	2.45	1.30	2.99	1.61	1.61	2.76	0.88	1.10
	0.032	0.037	0.060	0.034	0.078	0.041	0.048	0.077	0.061	0.032	0.074	0.040	0.040	0.068	0.022	
Na_2O	3.35	3.23	2.94	3.43	4.62	3.31	3.43	1.77	4.28	4.37	1.80	2.52	2.91	3.12	4.12	2.41
	0.054	0.052	0.047	0.055	0.074	0.053	0.055	0.029	0.069	0.070	0.029	0.041	0.047	0.050	0.066	
K_2O	1.48	1.55	1.95	1.55	1.59	1.23	1.67	1.38	1.38	2.78	0.39	1.53	1.48	1.17	1.66	0.96
	0.016	0.017	0.022	0.017	0.018	0.014	0.019	0.015	0.015	0.031	0.004	0.017	0.016	0.013	0.018	
H_2O	2.80	4.28	1.60	0.36	0.52	0.36	0.94	0.52	0.96	1.70	2.66	0.20	0.98	1.20	2.20	1.96
Cl.	0.0089			0.0071									0.0064	0.0018		
	99.81	99.23	99.51	99.45	99.44	99.30	99.61	99.87	100.63	100.59	99.79	100.40	99.77	99.63	99.78	99.09
Sp. Gr. 15° C.	2.503	2.327	2.610	2.769	2.687	2.635	2.440	2.468	2.440	2.352	2.268	2.539	2.464	2.647	2.462	

1. Hornblende-andesite, Mt. Stavro, Ægina.
2. Hornblende-andesite, Spasmeno Vouno, Ægina.
3. Hornblende-augite-andesite, West end of Mt. Chondos, Ægina.
4. Augite-hypersthene-andesite, summit of Mt. Oros, Ægina.
5. Augite-hypersthene-andesite, Mt. Kouragio. Ægina.
6. Hypersthene-andesite, summit of Mt. Chelona, Methana,
7. Hornblende-hypersthene-andesite, Kaimeni Stream, Methana.
8. Hornblende-andesite, segregation in No. 7.
9. Hornblende-dacite, Anzeiou, Ægina.
10. Hornblende-dacite, Kakoperato, Ægina.
11. Hornblende-andesite, segregation in No. 10.
12. Hornblende-hypersthene-dacite, near Panagia, Methana.
13. Hornblende-hypersthene-dacite, Kosona, Methana.
14. Hornblende-andesite, segregation in No. 13.
15. Biotite-dacite, Kolantziki.
16. Andesite Tuff (silicified), Mt. Chondos, Ægina,

type show the molecular proportions of the several oxides and will be referred to further on.

From these analyses, which include all the prominent varieties of the region except the Poros andesite, it is seen that we have representatives of almost all the members of the andesite and dacite families, and that on the whole they are quite normal in composition. Leaving the segregations out of account for the present it is seen that the range of silica percentage is almost the complete one for the two groups, varying quite gradually from 54.53 (No. 5) to 67.34 (No. 15), or even 68.91 in the dacite of Kalamaki.[1] The line between the dacites and the andesites is quite sharply drawn, though the dacite of Anzeiou shows an abnormally low percentage of silica (61.29). The other dacites, though, show quite normal amounts, and the dividing line may be drawn at 61 per cent. of SiO_2,[2] the most acid of the andesites, that of Poros, containing 60.21 per cent. (according to Lepsius, *loc. cit.*).

The presence of chlorine in all the specimens in which it was tested for is of interest and analogous to results obtained elsewhere in volcanoes very near the sea.[3] Attention may here be called to the much smaller quantity of Cl. in the segregation (No. 14) than in its surrounding rock (No. 13). The H_2O is in quite large amount in several, and is more than can be accounted for by perlitic groundmass. All the specimens, however, except No. 2, seemed quite fresh.

While both of the analyses of hornblende-andesite (Nos. 1 and 2) can be quite closely paralleled by analyses of the same species from other localities, yet they show *inter se* great differences in their percentages of silica and alumina. The very low silica content of the Stavro rock is the more surprising inasmuch as on account of the presence of tridymite, green hornblende and biotite and on other grounds, a considerably higher amount of

[1] Lepsius in PHILIPPSON, Pelop., p. 603. The SiO_2 determination in the Sousaki dacite is not counted here as the specimen was not fresh.

[2] The analyses of KÜCH (op. cit. p. 78) indicate about the same limit, his most acid andesite containing 62.26 per cent. SiO_2.

[3] Vesuvius, Anals. of Haughton, in ROTH. Beitr. z. Petr., 1884, p. lvi. Etna, Anals. of Ricciardi, *Ibid.*, p. lxxvi.

SiO_2 was to be expected. The very large amount of Al_2O_3 is also very remarkable, it being the largest of the whole series; and, since calculation shows that the extra amount of Al_2O_3 in No. 1, over No. 2, if determined as SiO_2, would bring the percentage of the latter in No. 1 up to 58.46 (*i. e.*, nearly equal to that of No. 2), while the other oxides in the two are in closely similar amounts, it is feared that a mistake has been made by the analyst. On this account (though with some hesitation) I have decided not to use analysis No. 1 in the further discussion of these rocks. The mistake suspected does not, however, affect the other constituents and we find them quite normal, the alkalies low, with Na_2O greater than K_2O, and the lime, in accordance with the character of the plagioclase, higher than both together; while the iron oxides and magnesia present no special features of interest, except that the ferric oxide is much higher than the ferrous.

In all the pyroxene-andesites (Nos. 3–7) the silica is low, though considerably higher in the last two, which are from Methana. Alumina in the Mt. Kouragio rock (No. 5) is extremely low, but elsewhere quite normal. The iron oxides are greater in amount than in any other group, the ferric oxide being either less or only slightly greater than the ferrous, which is due to the abundance of hypersthene; in the hypersthene-free andesite of Mt. Chondos (No. 3) the ferric oxide is, on the contrary, much more abundant. They are all rich in lime and magnesia but poor in alkalies, the large amount of lime being due to the basic character of the plagioclase.

The acid dacites show a normal amount of Al_2O_3, but are much poorer in lime and richer in soda than the other groups which bears out the conclusions drawn from the optical examination as to the character of the feldspar. The comparatively large amount of K_2O in the Kakoperato dacite (No. 10) points to the presence of some orthoclase as has been already mentioned. They are, on the whole, rather rich in iron and magnesia for the group, and in two cases the ferrous oxide is greater than the ferric.

The segregations are all low in silica and alkalies but high in

lime and magnesia, with alumina and the iron oxides quite variable. But a specially interesting point is the comparison of their analyses with those of their surrounding rocks of which three examples are given. The most striking fact is that in all three the segregations are more basic than their hosts, in one case the former containing 8.19 per cent. of SiO_2 less than the hornblende-dacite which carries it. They are also notably richer in lime, the same case as above containing 2.3 times as much as its host. They are also richer in magnesia. In general they are poorer in alkalies, though this not so prominent, but there seems to be no fixed relation as regards the alumina or the iron oxides. These results, which are what we would have been led to expect from the microscopical examination and our previous knowledge of segregations[1], confirm us in the belief that we have in these masses to do with true segregations (endogenous enclosures) and not (exogenous) enclosures.

Mention has already been made of the fact that the rocks of the Stavro district, Mt. Oros, Mt. Kouragio and Mt. Chelona are extremely poor in, if not quite free from, segregations, while on the contrary the dacites (with the exception of the Kolantziki rock and the Poros and Kaimeni andesites are rich in them. Now on referring to the analyses it will be seen that the rocks poor in segregations belong to the more basic members, while those carrying many of them are quite or very acid. The rocks of the Monastery District seem to occupy an anomalous position in this respect, since they generally abound in segregations, while at the same time the only one analyzed (No. 3 from Mt. Chondos) contains only 55.46 per cent. of silica. It must be noted, however, that the Mt. Chondos rocks carry fewer of these masses than the rocks of Mts. Gaiapha and Dendros, and it is possible that analysis of these last will show them to be richer in silica than No. 3.

Leaving these rocks then out of the question, the poverty of the basic rocks in the basic segregations points, like the consideration above brought forward, to the conclusion that these masses are

[1] Cf. Zirkel, op. cit, II., p. 788.

in reality segregations and not enclosures. In accordance with the theory of the differentiation of magmas the large masses of basic andesites as well as the smaller segregation masses are the products of such a differentiation process, so that the later ejected acid products would carry up with them parts of the later more basic differentiation products (the segregations) still remaining behind, while the main andesitic masses were ejected before these last were formed. That such is the true explanation is indicated by the fact that the segregations are, relatively to the neighboring basic rocks, richer in lime and magnesia, poorer in alkalies, and containing at the same time either exactly the same percentage of silica or even less (cf. Anals. 4 with 11, 6 with 8 and 14).

Again, if the masses in question were merely fragments of earlier now buried lava outflows, it is difficult to understand why the later basic streams of Oros, and the rest did not carry up fragments when such contiguous outflows as those of Kakoperato or Mt. Gaiapha did do so.

As to the specific gravities it will be seen that the more basic pyroxene-andesites are considerably denser than the hornblende-andesites or the dacites, and that the enclosures have likewise a decidedly higher specific gravity than their enclosing rocks.

Order of eruptions.—It has already been mentioned that, though the evidence at present available is scanty, the eruptive center of Ægina shifted as time went on from the south to the north. If, as seems probable, this be true, we find that the eruptions began with pyroxene-andesites and ended with more highly acid hornblende-andesites, the order of eruptions being, on the whole, one of increasing acidity. The establishment of this relation is of some importance, and we shall see whether the other occurrences of the region bear out the above conclusion or not.

The most striking and conclusive case is met with in the Oros district, where the certainly later flank eruption of Anzeiou and Kakoperato are much more acid than the earlier main outflows forming Mt. Oros. A similiar relation also obtains in the

Stavro district, where the later Spasmeno Vouno erupted material is more acid than the Stavro rock since, even making the alteration in the SiO_2 percentage mentioned further back, we find the acidity to be less than that of the former. The main Methana eruption also points the same way inasmuch as the earlier eruptions are all much more basic than the later flanking dacitic ones. One remarkable exception which has doubtless also struck the reader must, however, be noted. At Kaimeni the site of the very last eruption in the whole region, we should expect to find, in accordance with the rule above, a quartz-bearing dacite, perhaps like those of the mainland to the north; whereas we find a hornblende-hypersthene-andesite scarcely varying in chemical composition from the much older eruption of Mt. Chelona,[1] a gentle reminder that in the present state of our knowledge of the laws governing the chemical constitution of rocks generalizations must not be pushed too far.[2] While this exception is striking, yet it does not invalidate the rule enunciated above, and which we may regard as established for this region, that the order of eruptions was one of increasing acidity. The relation of these rocks to one another in time is that most usually observed among the several possible cases.[3] A closely parallel series of eruption products, though on a larger and more complete scale, has been described by Iddings[4] as occurring in the Yellowstone National Park. It is unfortunate that no data are at hand for determining the relative age of the rocks from any one group of the localities whose rocks are described by Küch and Belowsky, since their comparison would be of great interest owing to the many points of similarity between their specimens and those described in the present paper.

[1] It may be recalled that in the Kaimeni specimens are found a number of quartz grains which are conspicuously absent from the Chelona rocks.

[2] As Iddings has pointed out (Orig. Ign. Rocks, Bull. Phil. Soc., Washington, 12, 1892, p. 178) such reversions to an earlier type of differentiation products are not at all unusual.

[3] Cf. Zirkel, op. cit., I., pp. 810 ff.

[4] Erupt. Rocks of Electr. Peak and Sepul. Mt., 12th Ann. Rep. U. S. Geol. Surv., Washington, 1892, pp. 577–663.

To return to the analyses for a few moments, it will be seen on examination that the rocks of Ægina are, on the whole, notably less acid than those of Methana; the main mass of Ægina (excluding such small eruptions as those of Anzeiou and Kakoperato) being made up of andesites with a silica content not exceeding 56 per cent., while a large part of Methana is composed of dacites with over 61 per cent., and the most basic rocks have not less than 59 per cent. or more. This difference is most strikingly shown on comparing such similar rocks as those of Mt. Oros and Mt. Chelona, they being both hypersthene-andesites of very similar mineralogical composition. Here we find that the silica percentage of the former is 55.87, while in the latter it is 59.83. A similar result is reached on comparing the analogous rock of Mt. Chondos with that of Kaimeni, the respective SiO_2 percentages being 55.46 and 59.94. It may also be noticed that the dacites of Ægina are less acid than the dacites of Methana. When we look at these facts in the light of the law above laid down it follows that, on the whole, the eruptive activity of Methana most probably belongs to a later period than that of Ægina; which conclusion is supported by the fact that the only known historical eruption of the region took place on Methana, as well as by the absence in the latter of andesitic breccia cemented by tertiary limestone, and by the general appearance of the two islands.

Iddings[1] has endeavored to show that, as a rule, "the order of eruptions for any complete series of igneous rocks is from intermediate to more and more extreme varieties" (*loc. cit.* p. 183), so that at the beginning rocks such as the andesites are poured forth while at the close the eruptions are of basalt and of rhyolite; the exceptions being explained as belonging to unfinished progress of differentiation and eruption. While the exceptions are numerous and often not explicable in this manner, yet, in many localities, this law does undoubtedly hold good, and it will be of interest to determine whether this law also applies in the region which is the subject of this paper, as

[1] Orig. Ign. Rocks, pp. 144 ff.

well as at the volcanic centers situated on the same fracture line.

If we adopt Iddings' view it would seem, as the same writer has suggested in the case of the South American volcanoes,[1] that the volcanoes of the Ægina-Methana region are comparatively young and have not completed their full course of differentiation. Whether this course will eventually be completed, or whether for some unknown reason they have ceased activity forever, and will never reach the basalt and rhyolite stage it is impossible to say, though the latter is decidedly the more probable, as has been mentioned above.

But it must be remarked (as was pointed out by von Buch many years ago[2]) that basalt is entirely lacking along the whole volcanic line from Nisyros to Kolantziki.[3] On the other hand, rhyolite is said to occur on the islands of Kos[4] and Milos,[5] though in the case of the latter, owing to imperfect description and lack of analyses, its occurrence is somewhat doubtful. In these two cases the volcanoes are most certainly extinct, but no indication is given as to the relative age of the rhyolite as compared with the andesites which compose the other eruptive masses of the two islands. The volcano of Santorini is not yet extinct,[6] and here, to judge from the not very numerous good published analyses (which, moreover, do not cover the various varieties completely) it seems probable that the order of eruptions has followed the same law as in our district, the earliest rocks (those of Balos and Megalo Vouno and Thera) having been either

[1] JOUR. OF GEOL., I., p. 169.

[2] V. BUCH: Phys. Besch. d. Canar. Inseln. Berlin, 1825, p. 359.

[3] Basalt occurs to the north at Samothrace (NIEDZWIEDZKI: Min. Pet. Mitth., 1872, p. 107) and near Persufli in Thessaly (LEPSIUS: Geol. v. Attica, Berlin, 1893, p. 169), which we may suppose to be on a westward continuation of the Asia Minor line running from Armenia through Afium Kara Hissar and the Katakekaumene to the Troad and Lemnos, along which we know basalt to occur.

[4] DOELTER: Verh. Geol. Reichsanstalts, 1875, p. 233.

[5] EHRENBURG: D. Inselgruppe v. Milos, Leipzig, 1889, p. 102. ROTH: Geol. II., p. 229.

[6] The crater of Giorgio Kaimeni was in a solfataric state when I visited it in the spring of 1893.

shown by chemical analysis to be low in silica or else described as anorthite lavas,[1] while the latest outflows of Giorgio Kaimeni belong to the most acid pyroxene andesites.[2] But here again we have no trace of either basalt or rhyolite. As will be shown farther on, the rocks of Nisyros are probably similar to those described here, but scarcely anything is known of them.

Taking all the above facts into consideration, viz., the permanently extinct condition of Kos and Milos, and the almost as certainly extinct condition of our region, the total lack of basalts, almost total lack of rhyolites, and the overwhelming preponderance of intermediate andesites shading into dacites or very acid pyroxene-andesites,[3] and the not very basic character of the segregations, we may conclude that, while Iddings' law holds good for this region, it does so only partially; in that as the eruptions proceeded the magma became more and more differentiated, but that this process of differentiation never reached (as far as we can prove positively from the evidence of erupted materials), and probably never will reach, the extreme stages of basalt and rhyolite, the limits reached here being in one direction andesite with about 54 per cent. of SiO_2 and in the other dacites or andesites with 68–69 per cent. SiO_2.

THE REGION AS A PETROGRAPHICAL PROVINCE.

The scope of this paper as well as lack of space forbid my entering here into a complete discussion of the characters of the whole Ægina-Nisyros fracture line, but some remarks may be made on its general characters regarded in the light of a "petrographical province." As has just been pointed out the larger part of the eruptive rocks along this fracture line are pyroxene-andesites, with smaller quantities of hornblende-andesites, which, as the magma becomes more and more differentiated, run into highly acid andesites or else dacites, with perhaps some rhyolite.

[1] FOUQUÉ: Santorin, pp. 334, 341. Cf. ROTH: Geol. II., 362.

[2] Cf. ROTH: Beitr. Petr. 1869, p. cxxiv.

[3] It may be here remarked that as far as the published accounts and my own observations permit me to judge the eruptions near Smyrna and Pergamon were likewise confined entirely to andesites, and they are now certainly extinct.

The whole line is an excellent example of a petrographical province, the prevalence of hypersthene and colorless augite, and probably also the predominance of bytownite and anorthite among the feldspars, with absence of orthoclase, being some of the characteristics. But much work remains to be done in this direction along the whole line before we can feel justified in describing it.

The mineralogical and petrographical characters of the Santorini lavas are so well known that nothing further need be said of them here in this respect ; but from a chemical standpoint, while they were examined with great care by Fouqué, yet many of the analyses are so unsatisfactory, and they cover such a small number of the various occurrences, that our knowledge of them is still very incomplete.

From the short and not very detailed descriptions of Ehrenburg and Roth, cited above, it would seem that the augite, hypersthene, and hornblende-andesites of the Milos group closely resemble those of Ægina-Methana, even in small details such as the occurrence of the hypersthene, glass "net-work" inclusions in the feldspar phenocrysts, rose color of the quartzes, and so forth. Unfortunately Ehrenburg does not mention the color of the hornblende of the hornblende-andesites, and no information is vouchsafed us by either author as to the chemical composition of the rocks.

Again, Nisyros, since it was visited by Ross[1] in 1841, who spent two days there and gives a short account of it, seems never to have been visited, and certainly never described by a geologist. When Ross was there it was in a solfataric state, and he describes the crater, the lava streams flanking the mountain and forming promontories in the sea. He speaks of the lava as black and mentions much ash and pumice as strewing the surface of the ground, but from his account we can form scarcely an idea of the petrographical character of the rocks of the island.

In the course of some excavations at Platæa in Bœotia in 1889, however, I found fragments of large corn-grinders made of a

[1] Ross: Reisen auf den Griech. Inseln. Stuttgart. Vol. II. 1843, pp. 68–80.

dark lava, and similar objects made of the same rock were discovered during the excavations of the American School at the Heraion near Argos. The rock is dark gray in color, fine-grained and finely vesicular and shows a few small phenocrysts of hornblende and plagioclase, with one or two larger quartz grains. Under the microscope it is seen to be a hornblende-andesite with a hyalopilitic groundmass of colorless glass base and numerous plagioclase microlites showing flow structure, the rather abundant phenocrysts being chiefly yellowish brown hornblendes, altered opacitically on the borders, with some clear colorless augites and large plagioclase crystals, many showing a "network" core.

Microscopically it has a certain resemblance to some of the Ægina rocks, though neither megascopically nor microscopically is it identical with any of the rocks seen or collected by me at Ægina, Methana or Santorini, nor does it correspond to any of the descriptions of Doelter or Ehrenburg of the rocks of Kos or Milos. It seems then almost certain that it does not come from any of these islands. Now, Strabo[1] informs us that the island of Nisyros supplied the neighboring region with excellent millstones, so that it seems reasonable to suppose that the corn-grinders found at Platæa and Argos (which were Strabo's millstones) came from Nisyros. If this be so it would go to show that Nisyros has been ejecting much the same sort of rock as the volcanoes further west on the same line, which is *a priori* to be expected. It is needless to remark that the above argument is of very little weight, and it is chiefly inserted to emphasize the slightness of our knowledge of the Nisyros rocks.

However, leaving aside for the present the other volcanic centers of the fracture line, let us examine more closely the rocks of our present region. For this purpose I have constructed the diagram of the molecular variation of their constituents as shown in Diagram 1. The molecular amounts of silica are given by the abscissas, the limits of the diagram extending from .850 to 1.150. The iron oxides are given as FeO. In the upper part the six

[1] STRABO: Geogr., X. 5–16.

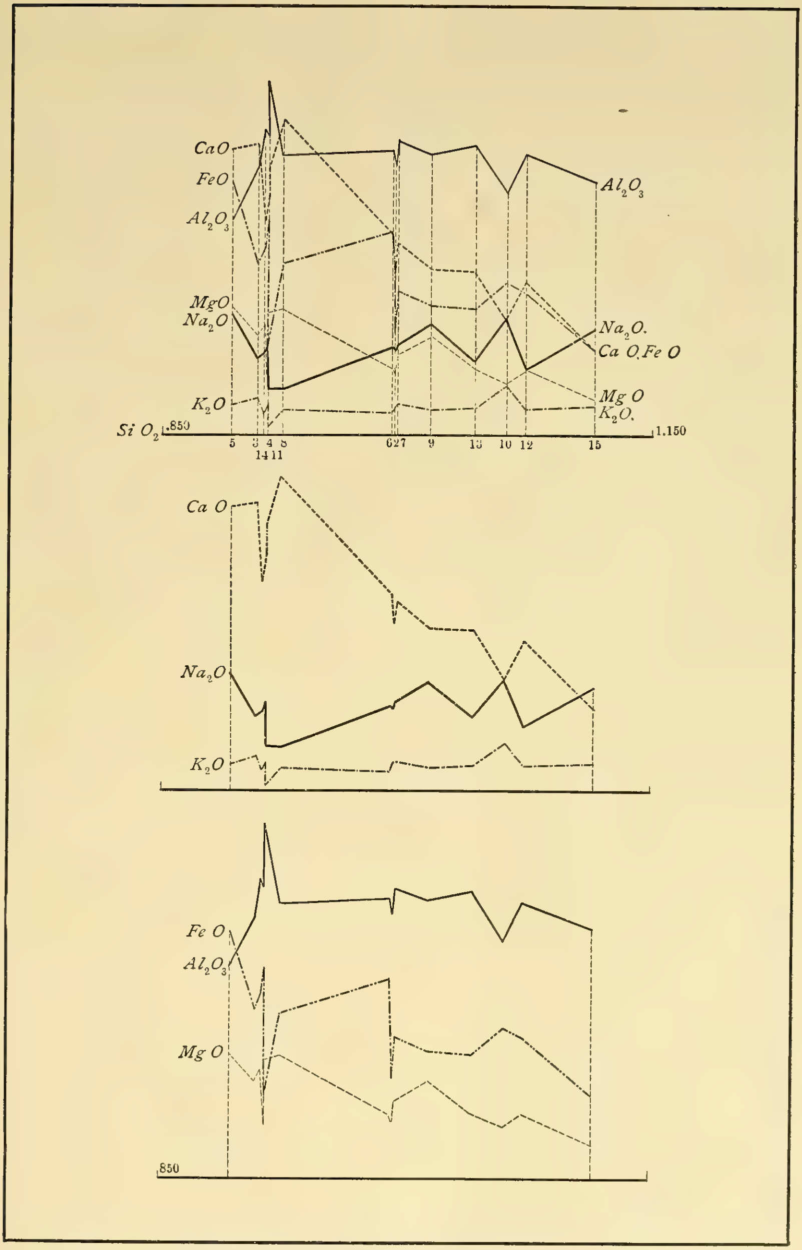


DIAGRAM I.—Molecular variation of the rocks of the Ægina-Methana region.

main constituents (except SiO_2) are plotted together, while in the two lower sections they are given in two parts to avoid confusion and bring out more clearly some of the features of interest. I have arranged them somewhat differently from Iddings' previous diagrams, grouping together the CaO, Na_2O and K_2O, since these elements occur most prominently together in the feldspars, FeO and MgO occurring together in the ferro-magnesian silicates, and with these last two I have placed the Al_2O_3.

It is seen from this that alumina occupies a very high position though with considerable variation. In the more basic rocks it is surpassed three times by the CaO, which in this part of the diagram varies inversely as the Al_2O_3 does, while later the two lines run almost parallel, the CaO being considerably lower, and dropping a great deal as the SiO_2 increases. CaO and MgO run also approximately parallel, though the drop in MgO is less than in the other, and the inverse variation of Na_2O to both is well seen, especially with CaO and Na_2O in the middle section. K_2O follows the Na_2O line fairly closely, but its variations are always less than those of the other constituents, and it remains throughout in the lowest position, Na_2O being at least twice and often more than three times as great. It may be noted that in only two cases do the molecules of Na_2O and K_2O sum up more than those of CaO. Al_2O_3 and FeO also vary inversely at the very end, where there is a considerable drop in the FeO. MgO and FeO have quite similar lines, though at one point their variation is inverse, the latter maintaining an almost constant lower position. MgO varies on the whole inversely to K_2O and still more markedly so to Na_2O.

The relations of the segregations to their enclosing rocks is beautifully shown; the three segregations come also together near the basic end, while the three hosts come nearly together towards the acidic end; the richness of the segregations in lime and magnesia, their poverty in soda, and the variable character of the alumina and iron being well brought out.

Attention has already been called to the fact that the Ægina-Methana rocks show many points of resemblance to those of

TABLE II.

Analyses of Lavas of Santorini.

	1	2	3	4	5	6	7	8	9	10	11	12
SiO_2	51.7	52.4	53.9	56.0	57.2	60.9	64.6	66.15	67.05	67.24	68.12	68.39
	.856	.868	.892	.927	.947	1.008	1.069	1.095	1.110	1.113	1.128	1.132
Al_2O_3	22.4	21.3	25.6	23.5	19.5	21.6	18.7	15.15	15.49	13.72	14.52	15.07
	.219	.209	.251	.230	.191	.211	.183	.148	.152	.134	.142	.148
Fe_2O_3	7.4	8.7	5.7	5.3	9.2	4.3	6.2			1.90		4.26
FeO								6.81	5.77	0.85	5.73	3.83
	.093	.109	.071	.066	.115	.054	.078	.095	.080	.036	.080	.106
CaO	10.4	11.8	6.8	6.7	5.7	4.2	2.8	3.48	3.48	3.46	3.68	3.19
	.186	.211	.121	.120	.102	.075	.050	.062	.062	.062	.066	.057
MgO	4.3	3.9	1.9	2.6	3.1	1.5	1.5	1.08	0.77	1.22	0.64	0.70
	.106	.097	.047	.064	.077	.037	.037	.027	.019	.030	.016	.017
Na_2O	3.4	1.8	3.4	5.5	5.2	4.6	4.7	5.22	4.65	4.90	4.96	3.86
	.055	.029	.055	089	.084	.074	.076	.084	.075	.080	.080	.062
K_2O	0.4	0.1	2.7	0.4	0.1	2.9	1.5	2.19	2.34	2.57	2.23	0.73
	.004	.001	.030	.004	.001	.032	.017	.024	.026	.028	.025	.008
H_2O									0.47	0.54	0.43	
	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.08	99.94	100.59	100.31	100.03

1. "Anorthite Lava," Dike 20, Thera. Fouqué, Santorin, p. 332.
2. "Anorthite Lava," Dike 34, Thera. " " p. 332.
3. "Labradorite Lava," Dike 32, Thera. " " p. 333.
4. "Anorthite (?) Lava," Little St. Elias, Thera. Fouqué, Santorin, p. 334.
5. "Basic Lava," Balos, Thera. Fouqué, Santorin, p. 343.
6. "Labradorite Lava," Dike 49, Thera. Fouqué, Santorin, p. 333.
7. "Labradorite Lava," Dike 53, Thera. Fouqué, Santorin, p. 333.
8. Pyroxene-andesite, West May Island. Roth. Beitr. z. Petr., 1869, p. cxxiv. No. 11.
9. Pyroxene-andesite, Nea Kaimeni. Roth. Beitr. z. Petr. 1869, p. cxxvi. No. 12.
10. Pyroxene-andesite, Giorgio Kaimeni. Roth. Beitr. z. Petr. 1869, p. cxxiv. No. 2.
11. Pyroxene-andesite, Thera. Roth. Beitr. z. Petr. 1869, p. cxxvi, No. 14.
12. Pyroxene-andesite, Giorgio Kaimeni (?). Roth. Beitr. z. Petr. 1869, p. cxxiv. No. 10.

Colombia and Ecuador in their chemical composition, their structure, their mineral composition and in their segregations, even down to small details. It will hence be instructive to compare the diagram of the molecular variation of the present rocks with those of Colombia and the Andes volcanoes (especially the former), which Iddings has already published on pages 173 and 174 of Vol. I. of this journal.

On comparing the diagrams great differences are at once apparent. In the first place in our region the Al_2O_3 line, while on the whole the highest, is crossed at the basic end by both CaO and FeO, whereas in Iddings' diagrams it is far above all the others, and moreover drops notably more toward the acidic end than in the present diagram. In the South American rocks it runs much more parallel on the whole to CaO than in ours and is also markedly parallel to FeO, while in the Greek rocks the two are inverse throughout almost their entire course. Al_2O_3 and Na_2O are decidedly inverse in both regions, but in the South American rocks the two alkalies are inverse (especially in the Colombian rocks), while in Greece they are parallel. Another striking point of difference is the behavior of the CaO, MgO and FeO molecules which in both of Iddings' diagrams run close together and in the Andes rocks especially are much intertwined; in the Greek rocks on the other hand they run quite far apart from each other.

Further study of the diagrams will reveal many more points of dissimilarity, but those mentioned are sufficient to show that the rocks of the two regions are differentiation products of widely different magmas; in other words that the two petrographical provinces are fundamentally distinct. The same differences are also seen on comparing our diagram with that of the rocks of the Yellowstone National Park given by Iddings,[1] and which he remarks show a great similarity to those of the Andes rocks. The diagram here given may also be instructively compared with those rocks from other localities given in the same paper.

[1] Orig. Ign. Rocks, Pl. II. I was unfortunately unable to consult the paper by DAKYNS and TEALL (Q. J. G. S. 48, 1892, p. 104) quoted by him in JOUR. OF GEOL. I., 170.

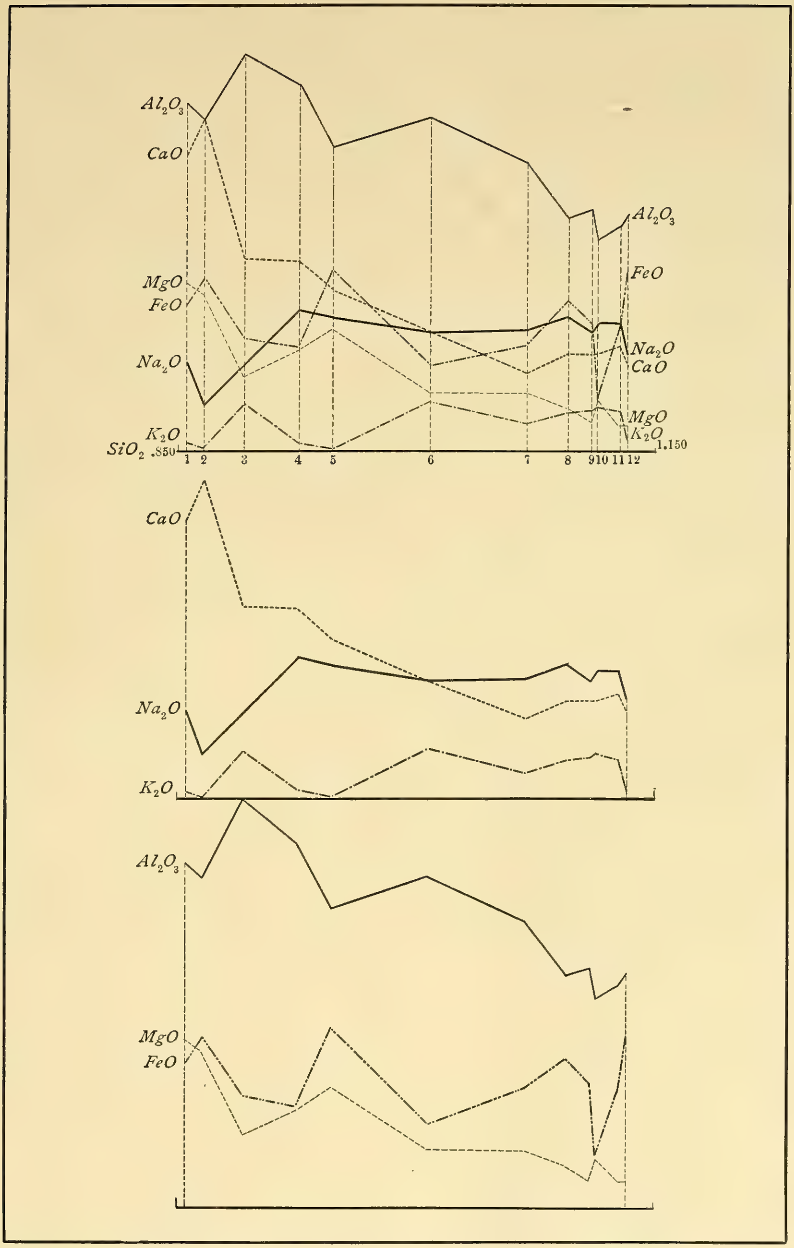


DIAGRAM 2.—Molecular variation of the lavas of Santorini.

Such differences in the fundamental chemical relations of the rocks of two widely separate regions are of very great interest especially, as Iddings has already pointed out,[1] as showing that the great bodies of magma beneath various volcanic centers or fracture lines differ radically from each other in chemical composition, and that the ideas of the consanguinity of rocks and the differentiation of magmas are true ones and based on deeper and more real distinctions than differences in mineralogical composition or the habit of the component minerals, which seems to have been the main idea in the minds of the originators of the term "petrographical provinces."[2]

In order to test this view further and set the reality of the term "petrographical province" more clearly and convincingly before the reader, I prepared Diagram 2, which represents the molecular variation of the eruptive rocks of Santorini, as given by the analyses shown in Table II. This diagram can only be regarded as an attempt at expressing the relations between the Santorini rocks, since Fouqué's analyses are most unsatisfactory (as is evident from an examination of them) and the probably more correct analyses quoted by Roth chiefly embrace the more acid rocks of Thera and the later eruptions. More analyses of the various lavas of this group are much to be desired and a diagram prepared from them would be much more conclusive than the present one.

Notwithstanding the unsatisfactory character of the analytical material the resulting diagram surpassed my expectations in regard to the similarity between the two districts, the two showing the same character in almost every respect, even down to details. The similarity will be evident at the first glance and the remarks on Diagram 1 will answer for Diagram 2, but to make it more emphatic I may call attention to a few points.

Na_2O and K_2O are in both beautifully parallel and with much the same habit, though in the Santorini rocks they drop a little at the acidic end, which, it must be remembered, is slightly higher

[1] Orig. Ign. Rocks, p. 135.

[2] VOGELSANG, Z. d. d. Geol. Ges. 1872, p. 507. JUDD, Quart. Jour., Geol. Soc. 1886, p. 54.

here than in the other.[1] CaO and Na_2O are beautifully inverse in both, except at the acidic extremity on Santorini where they both drop slightly together. They also cross in these rocks, soda becoming higher than lime at this end. FeO and MgO show the same kind of parallelism, and both are inverse toward Al_2O_3 throughout nearly all their length, but with the parallelism at the acidic end (especially between FeO and Al_2O_3) well shown in the two diagrams. The inverse variation of Al_2O_3 and CaO at the basic end and their parallelism toward the acidic end is well marked in both. But the above are sufficient, and further examination will only bring out more clearly the extremely similar character of the two lavas.

It would be most interesting to draw our conclusions from an examination of the diagrams given as to the character of the original magma, but it will be better to wait until a more satisfactory diagram can be drawn for Santorini with, if possible, one of Milos and Nisyros. By studying such a group of diagrams from a well defined volcanic fracture line the conclusions we might arrive at would be more valuable than those derived from less complete material. It may be worth remarking though, that, judging from these two examples, we can assert with much confidence that the rocks of Milos and Nisyros will be found to furnish diagrams resembling in their main features, if not in details, those given in this paper; that their general petrographical characters will be found to be very similar to those of the Ægina-Methana region, and also that the so-called rhyolite of Milos is in reality a dacite.

In conclusion, I may say that the two diagrams given here are sufficient to prove conclusively that not only do the eruptives of Ægina-Methana and Santorini belong to the same petrographical province, *i. e.*, are derived from the same main body of magma (which was *a priori* to be expected), but that this petrographical province has a magma quite different from that of the

[1] Compare the K_2O lines of these diagrams with those in the diagrams of the rocks of the Andes and the Yellowstone National Park, where the most acid rocks are rhyolites.

Andes, which was *a priori* not to be expected, since their solidified differentiation products (the lavas) so much resemble each other when examined individually by the usual petrographical methods. From this point of view such a comparison as has been here attempted is of special interest as going to show that the various bodies of magma beneath the earth's crust which supply the different volcanic centers are not identical,—parts of only one large interior mass,—as some have maintained who base their opinion on the superficial resemblance; though future research may show that these separate bodies of magma are themselves differentiation products of one original magma mass. But only a beginning has been made in the investigation of the differentiation of rock magmas, and, with Professor Iddings, I must put in a plea for fuller sets of analyses of the eruptive rocks from the various volcanic centers of the globe, as only such complete sets can furnish the data requisite for solving some of the problems that confront us.

HENRY S. WASHINGTON.

ON CLINTON CONGLOMERATES AND WAVE MARKS IN OHIO AND KENTUCKY[1].

WITH A RÉSUMÉ OF OUR KNOWLEDGE OF SIMILAR OCCURRENCES IN OTHER SILURIAN STRATA OF THESE STATES, AND THEIR EVIDENCE UPON PROBABLE LAND CONDITIONS.

CONTENTS.

[1] Continued from Vol. III., No. 1, p 50.

PEBBLES AND WAVE MARKS IN THE ONEIDA, MEDINA, AND CLINTON GROUPS.

The Medina of Ohio and Kentucky furnishes so few facts of interest in this connection, and in places so difficult to distinguish from the Clinton, that it will not be considered separately but will be discussed under the above heading.

Observations of the Kentucky Survey.—No *Oneida* is exposed in Ohio. In Kentucky a conglomerate two inches thick, with the characters ascribed to the Oneida conglomerate of New York, is found in Boyle county.

Medina.—The rock supposed by Kentucky geologists to belong to the Medina is exposed in Lincoln county. Here it reaches a maximum thickness of 35 feet. In the western part of the county it is thinner. The whole series has the appearance of having been deposited largely or entirely by currents, and sometimes, probably, in the face of waves, as at several points one or two layers have a wave-like structure. In Garrard county the Medina has a maximum thickness of 35 feet, decreasing towards Madison county, northeastward. In Clark county the total thickness of the Medina is probably 20 feet, including nine feet of sandstones and shales at the bottom, and 11 feet of limestones and shales at the top. Eastward, in Montgomery county, these shales increase in thickness. Only 10 feet are accredited to the Medina in Bath, while 20 feet are given for Fleming county, and the same thickness, 20 feet, also for Mason county.

The Medina in Marion county measures only 14 feet. In Washington county it seems to occur with a thickness of 30 feet in one case, but another section gives 14 feet. In Nelson it varies from three to 20 feet. In Oldham county it varies from 10 to 30 feet.

Taking into consideration only the area between Marion and Bath counties, the Medina seems to thicken towards the southeast. Between Washington and Oldham counties its thickness is very variable, and in Fleming and Mason counties the thickness is apparently greater than in Bath on the south, and certainly surpasses that of known exposures in Ohio. Wave

marks are mentioned only from the most southern county—Lincoln. This fact should be considered in connection with the occurrence of the Oneida conglomerate in Boyle county, another very southern county.

Clinton. a, Crab Orchard Shales.—These shales reach a maximum thickness of 40 feet in Lincoln county. Intercalated among them are a few hard, smooth plates of thin limestone. These plates, and sometimes the shales, have a curved structure, and at times some of the laminæ overlap the thinned-out edges of the others. In Garrard county they vary from 16 to 25 feet. In Clark county these shales are only seven feet thick. They occur in Montgomery county, but their thickness is not mentioned. The shales appear in Bath county, but form there the lower part of the recognized Clinton Group, and will not be discussed in this connection. In Marion county the thickness is 20 feet. In Nelson county has diminished to two or three feet.

The presence of the Crab Orchard shales as a representative of the Clinton is of interest chiefly in showing the general thickening of such detrital deposits southward.

b, Clinton, Proper.—Above the Crab Orchard shales, in Montgomery county, there are rough-bedded heavy limestones. The massive layers overlying the shale are somewhat heavier, and in one or two places one of them shows a wave-like structure with large ridges. Rarely there is a layer of even-bedded stone. The same wave-marked layer occurs in Bath county, three feet above the shales, and 18 feet above the base of the Clinton. It is from 10 to 14 inches in thickness, marked with ridges from four to six inches in height and about 26 inches from crest to crest. The ridges are not a regular curve, but are somewhat sharpened at the top. This wave-marked layer occurs with the same persistence and at the same horizon in Fleming and Lewis counties. It is probably the layer discovered by Locke in the Clinton near West Union, Ohio, to which reference will be made later.

The oölitic iron ore is quite characteristic of the Clinton along the eastern side of the Cincinnati anticlinal axis, and its

Kentucky extension. In the report on Garrard county the statement is made that some "shot" iron ore comes from some place in the Crab Orchard shales, but it was not found. Red hematite iron ore, the oölitic variety, is mentioned from northeastern Clark and Montgomery counties. The oölitic iron ore is well characterized in Bath county and is definitely located there about four feet above the wave-marked layer and about 23 feet above the base of the Clinton. It varies in thickness from a few inches on the Montgomery line to nearly three feet on the eastern side of the county. In Fleming county it is sometimes absent, and sometimes appears at its proper horizon, but very much diminished in thickness. It is seen also in Lewis county, and is well shown at various localities in Ohio, where it also occurs only along the eastern side of the anticlinal axis. Its occurrence usually a short distance above the wave-marked layer may be of some significance. The fact that the wave-marked layers and the oölitic ore in both Ohio and Kentucky are confined to the eastern side of the axis is certainly very suggestive as to the conditions under which the Clinton was deposited there.

Chert is found in the Clinton in Henry county, the horizon not stated. In Nelson it occurs towards the top of the Clinton. In Marion county it is common. Its best development however seems to be in the northeastern counties, in Bath, Fleming, and Mason, where it occurs in the heavy limestones toward the base of the Clinton. This same horizon it occupies in Ohio. In Bath county, the general thickening of these heavy beds eastward is noted.

For the sake of completeness, two peculiar occurrences should be noted, which deserve fuller study in the field. Near Fredericktown, on the western side of Washington county, several inches of conglomerate occupy a position just underneath the heavy limestones of the section, presumed to be the Niagara. This would place it at the top of the Clinton. The conglomerate was composed of fragments of iron ore, probably the remains of the Clinton iron ore beds, cemented in a sandy shale. This conglomerate probably once extended over the entire country. In

Garrard county, above the Crab Orchard shales, occur one or two layers of limestone, which contain small rounded grains of clear quartz. Both of these occurrences are in southern counties, and they are probably good indications of strong wave action, with shallow waters, at the close of the Clinton age in this direction.

Observations of Dr. John Locke.—The locality in the Clinton investigated is along Lick Run, three to four miles northeast of West Union. This is 12 miles a little east of south of Elkhorn creek, and 50 miles east of south from the Todd's Fork locality. Waved layers were found. These are mentioned on page 244 and on plate 6 of the first report of the Geological Survey of Ohio, 1838. According to the section two waved layers, 20 inches apart, were found. It seems difficult however to believe the occurrence of the flinty layer at the top of the Clinton. The region near West Union would probably offer information pertinent to the present subject.

OBSERVATIONS BY THE WRITER IN OHIO.

Todd's Fork.—About two and a half miles north of Wilmington, the pike to Xenia crosses Todd's Fork. In the immediate neighborhood, along the stream, are numerous exposures of the Dayton limestone and of the top of the Clinton. Their junction can be best studied by following the stream eastward a short distance. Towards the top of the Clinton is found the peculiar brown purple rock also seen at Wm. Alexander's near Sharpsville. It contains in places the peculiar branching masses of fragmental material resembling the so-called fucoidal markings, also seen at Alexander's. In other courses of this purple rock, just beneath the Dayton limestone, was found a new brachiopod, a Craniella. The ferruginous red rock, so abundantly exposed a mile down the stream, was not seen here. Under the purplish layers the rock is brownish in color and contains numerous fossils. Going down the stream from the Xenia pike bridge, exposures of the Clinton are abundant. Wave marks were not seen at all. At several points cross-bedding is very marked, especially opposite a house belonging to Isaac Cline, of Wilming-

ton, but now inhabited by E. D. Miars. Nearly opposite, but a little down stream, a few stray pebbles were found in the Clinton. In order to satisfy myself that I was dealing with genuine pebbles and not with concretions, accidental layers of peculiar character, or rolled stromatoporoids, it was necessary to break open most of these. But on the south side of the stream occur two pebbles whose character would be acknowledged by any geologist, the larger one being 7½ inches long, 5¾ inches broad, and 1½ inches thick. Since the chief value of these pebbles lies in the fact that they are *in situ*, they were indicated by a mark pointing towards them, and it is hoped the pebbles will not be removed by visiting geologists. Pebbles were very scarce in the Clinton, only about six pebbles were found whose character was unequivocal. They were evidently derived from the Clinton layers immediately beneath. Following the stream southwards, nothing of special interest occurs until we reach the well-known Todd's Fork section, described in an earlier paper. It is on the north side of the stream, about three hundred feet east of the bridge, by which the Quaker Centre pike crosses the fork. Here the ferruginous, red-brown, oölitic, fossiliferous Clinton is well developed at the top of the section, these characters disappearing on going downward in the section, so that six feet below the top the rock is pinkish in color and has but few fossils. The Clinton section is here 18 feet. The lower two-thirds is light pink in color, and contains few recognizable fossils, although on closer examination the rock is seen to be a mass of crinoidal fragments, consisting especially of pieces of the narrow stem of some crinoid. Associated with the ferruginous layer is some of the purple tinted rock already mentioned. In it was found a thin pebble, consisting of the iron-stained limestone found immediately below. All of the pebbles found in the Clinton of Todd's Fork resemble the Clinton rock lithologically. In the pinkish rock, forming the lower two-thirds of the Clinton, evidences of stratification are in places rather common; at a few places a sort of cross-bedding was noticed. This can be seen at the Todd's Fork section just mentioned, and also up stream a short distance

east from Miar's house. Under the Clinton, at the section, the Medina is found, five feet thick, containing annelid teeth towards the top. Beneath this are said to be about eight feet of blue clay, some of which can be seen on the north side of the creek, after following the stream westward for some distance.

The small number of the pebbles found should be especially noted.

Farmer's Station.—On the Baltimore & Ohio Railroad, fourteen miles a little east of south of the Todd's Fork locality. Going south from the station on the Lynchburg pike a little over a quarter of a mile, then diagonally eastward by a road coming in from the left, crossing a bridge across a small stream, the house of Anderson D. Johnson, formerly the home of George Grubb, is reached. It is about half a mile from the station. Directly west of the house, in the bed of the stream just mentioned, the base of the Clinton is found exposed (locality 1). Large fragments collected upon the banks show this rock to vary, some courses being blue and compact, weathering drab, others being naturally more whitish, and fairly fossiliferous. The fossils were: Proetus determinatus, head, distinct; Illænus ambiguus, pygidium; Lichas breviceps, glabella; Phacops trisulcatus, heads and pygidia, rather common; Dalmanites Werthneri, a good head; Leptæna rhomboidalis, middle size; Strophomena (Strophonella) patenta; Orthis elegantula, var. parva; Ptilodictya lanceolata, var. Americana; Phænopora simplex, nov. spec. the form with simple fronds, slightly curved, otherwise having all the appearance of a single branch of *Phænopora multifida.*

Some slabs show round blotches, one-half inch to one inch in diameter, now brownish clayey masses; these may once have been limestone pebbles which decayed more rapidly than the cementing limestone. There was no *good* evidence of the former existence of pebbles in these rocks. The presence of cherty slabs showed how far north this element of the more southern exposures of the basal Clinton extends. Sometimes fossils occur both above and below in immediate contact with the chert,

sometimes preserving their original calcareous shell. Farther north, on the east side of the creek, a hole dug in the side of the hill (locality 2) showed a more massive and more ferruginous rock, many crinoid beads, belonging to the Middle and Upper Clinton. No good section is exposed.

Sharpsville.—Seventeen and a half miles slightly east of south of Wilmington, and about three miles a little north of east of Lynchburg; in the northwest corner of Highland county. The section starts at the east and west road, about two-thirds of a mile north of Sharpsville, near the house of Wm. Alexander. Nearly opposite the house, on the south side of the road, is a quarry opened up into the Dayton limestone (locality 3). The base of the Dayton limestone here contains Favosites favosus, both the large and small varieties according to Rominger, a branching compound coral, crinoid stems, and a few other fossils, more or less frequently. Immediately under the Dayton limestone is found the deep red ferruginous Clinton. This is best exposed in the little streamlet southeast of the quarry. Eastward along this stream (locality 4) the top of the ferruginous Clinton presents a lithological characteristic difficult to describe, except that it is a sort of consolidated marl of peculiar color. This marl surface contains a number of fossils characteristic of the so-called Beavertown marl, overlying the Clinton south of Dayton and also south of the Soldiers' Home. These are Raphistoma affine, Cyclora alta, Loxonema subulatum? one of the small Tellinomyas, Orthis biforata, Orthis elegantula, Orthoceras inceptum, and Calymene vogdesi. Of these fossils the Raphistoma and Orthoceras were also found in the ferruginous Clinton at Todd's Fork. The present locality is the most southeastern exposure, containing the Beavertown marl fauna, so far known. This ferruginous rock is about two feet thick, and is underlaid by a pinkish rock containing many crinoid stems, Platyceras (Platystoma) niagarense, the small Soldiers' Home form, and Orthis elegantula, corals, and Rhinopora verrucosa. This pinkish Clinton is well shown in the field east of the house of Daniel Sharp, along the more southern parts of the streamlet above

mentioned. Above the pinkish Clinton, the ferruginous Clinton at times shows dark red sandy phases in which Rhynchonella acinus var. convexa is often a common fossil, even the calcareous shell being at times preserved. This phase may be seen over the pinkish Clinton, southeast of Sharp's house, between the house and the stream. Farther southward is the fairly extensive quarry of Daniel Sharp, where the Dayton limestone is well shown (locality 5). Passing the quarry and descending the stream, the fence separating the land of Daniel Sharp from that of A. K. Johnson is reached (locality 6). The fence rested upon a whitish limestone block containing limestone pebbles, of a character lithologically similar to the rock belonging to the Lower Clinton of this section. From this point on, for a considerable distance down the stream (to locality 7, which is a heap of boulder fragments), boulders of Clinton rock containing pebbles are of more or less frequent occurrence. Since they are not found in the *in situ* exposures of the Lower Clinton seen along Turtle creek, which will be described later, it is evident that the boulders belong to the Middle Clinton. At the fence above mentioned, the cement of the pebble-bearing rock contained Illænus ambiguus, Meristella umbonata and Orthis biforata, var. daytonensis. Farther down, the cement contained abundant and characteristic Clinton fossils. The pebbles were often of fair enough size, at times five or six inches in diameter. The pebbles resemble lithologically the more sandy Clinton beds just beneath. Continuing southward, the stream enters Turtle creek. Following its course downward or westward, a continuous line of exposures is found along the northern bank opposite the cluster of houses called Sharpsville. The total exposure includes a section of 13 feet. Beginning nearer the eastern end of the exposures (locality 8) and going downwards, we have at the highest point 16 inches of a sandy stratified limestone; then 12 inches of solid white limestone with fossils; 13 inches of sandy stratified limestone; six inches of whitish solid fossiliferous limestone; 30 inches of sandy, well stratified limestone; one inch of chert; two inches of sandy limestone; two to three inches of white chert; 24

inches of unevenly-bedded rock with fossils; one inch thickness of a thin, sandy layer, very undulated, like ripple marks where waves have crossed from various directions. Their importance was not appreciated, when observed, and their direction was not carefully observed. Judging from the memory alone the larger ripples had a general northeast course and indicated currents transverse to this direction. Below this layer were found 10 inches of a whitish rock, lithologically like the Dayton limestone, and like it, with a very uneven surface to the upper side of the layer. Tracing this layer westward to the more western part of this line of outcrops as far as a place known as John Arment's quarry (locality 9 in the bed of the creek), the cherty layers beneath the same are well exposed. First there is a layer of white chert four inches thick, then four inches of a brownish rock, then four inches of chert again, and finally 24 inches of limestone, whitish above becoming bluish below, and quite fossiliferous, though hardly more so than some layers farther up in the series. In this basal layer of the Clinton the following fossils were found: Illænus ambiguus, Orthis biforata, Ptilodictya lanceolata, var. americana, Clathropora frondosa, Phænopora magna, Rhinopora verrucosa, and Phylloporina angulata.

Underneath the Clinton lie four feet of a bluish rock, the so-called Medina, which is here quarried. It contains, in addition to the so-called branching fucoidal impressions, a species of Orthis, on the type of Orthis calligramma, but with about 44 radiating plications, and annelid teeth. The Orthis does not closely resemble the more nearly related Clinton species. It will be remembered that annelid teeth also occurred in the so-called Medina at the Todd's Fork locality.

Under the Medina is a bed of blue clay, but its thickness has not yet been determined. The Cincinnati rock can not be far beneath.

Unfortunately it was impossible to determine, with the means at hand, the thickness of this section. It is hoped some one may undertake this. But it was difficult for the writer to believe that the thickness of the entire Clinton even approached 50 feet,

the thickness usually assigned to the Clinton in its southeastern exposures.

Rocky Fork.—On the pike leading to Belfast, one and a-half miles from Hillsborough. At the bridge, on the south side of the stream, the top of the Clinton is shown, underlying the Dayton limestone. East of the bridge, the east bank of the stream gives good exposures. Only a hasty observation was made. The fossils found, such as Orthis elegantula, were not conclusive. The strongly ferruginous character of the rock, especially an oölitic iron layer thinly interstratified at one place, in connection with its position beneath the Dayton limestone, sufficiently identified it. The writer failed to trace the Clinton eastward along Rocky Fork, but on the contrary found evidence of chert beds belonging to horizons quite a distance above Dayton limestone, at the lowest exposures next seen on going up stream. In this chert Encrinurus ornatus, Hall, was well shown in one case. An associated rock contained abundant Meristellas, much shorter than Meristella cylindrica, as seen in full-sized cabinet specimens from Hillsborough. Bisher's dam is only a short distance down stream from the bridge, and no very good reason can be seen there why the Clinton should not continue to be exposed for some distance down the stream. Unfortunately the writer had not the time to search in this direction.

Belfast.—Thirty-four miles southeast of the Todd's Fork locality, and 17 miles southeast of Sharpsville.

I. *The William Haigh Farm section.*—Going north along the road through Belfast, about half a mile from the center of the village, and then taking the first road going westward, a little stream, crossing the road, is soon reached. Following this stream southward, the Dayton limestone is found exposed in the creek bed, within a short distance of the road (locality 10). Continuing down stream the following very characteristic section is exposed. Beneath the Dayton limestone is the ferruginous crinoidal Clinton, containing Leptæna rhomboidalis, Phænopora multifida, and Rhinopora verrucosa. Within 200 feet of the road the ferruginous layer is conglomeritic, the pebbles being

of variable diameters, up to three inches. The pebbles now have the appearance of consolidated brownish clayey material; one of the pebbles contained oölitic grains similar to those of the general ferruginous rock in which these pebbles were imbedded. Three hundred feet from the road are bluish, sandy, stratified, non-fossiliferous layers similar to those near the top of the Turtle Creek section near Arment's quarry. A little further down stream the crinoidal rock contained pebbles, and one of these was made up of the same purplish ferruginous marl which constitutes part of the uppermost ferruginous layer of the Clinton in the present section. These pebbles were probably obtained from the Upper Clinton, not far distant. Farther down stream the rock contained Platyceras (Platystoma) niagarense, the little Soldiers' Home form, and Orthis elegantula. Six hundred feet from the road Illænus daytonensis, Orthis biforata, and Orthis elegantula were found in a whitish limestone; a single blue limestone pebble was seen. About 650 feet from the road good cross-bedding was noticed in the sandy stratified Clinton on the east side of the creek. In one layer the stratification lines dip 25 degrees southward; immediately overlying this layer is one with perfectly horizontal stratification. Farther down stream the rock becomes more massive, with few fossils, but opposite the barn it contains Clathropora frondosa, and a few stray bluish pebbles, two to four inches in diameter, lithologically similar to the Clinton rock immediately above and below. In a layer full of crinoid beads, together with Orthis calligramma, var. eu-orthis, Strophomena patenta, and Phænopora expansa, was found a stray small blue pebble one inch in diameter. Just below, opposite Wm. Haigh's house (locality 11), were found Illaenus ambiguus, Leptæna rhomboidalis, Strophomena tenuis, Orthis biforata, var. daytonensis, the larger form of those with three plications on the median fold. Below the house in the creek bed were slabs containing very small pebbles, up to one inch in diameter; Cyclonema bilix was seen here. Below this rock comes the very siliceous but not cherty rock which here constitutes the base of the Clinton. On the opposite side of the

creek a somewhat higher exposure shows four inches of chert overlying 24 inches of the sandy stratified Clinton. The structure of these elements of the basal Clinton can be better understood by a reference to the Smart section, next given. Underneath the Clinton on the west side of the creek are four feet of a massive greenish rock, constituting the so-called Medina of northern sections, and also containing the same annelid teeth, although in order to find these readily it is necessary to go southeastward to the southwestern angle of the hill caused by the cutting action of this small stream and the fork of Brush creek, a short distance to the southward, into which the stream flows (locality 12). Beneath the Medina are 22 inches of a bluish clayey material, which, however, has become somewhat indurated, and presents a shaly structure instead of the usual homogeneous clayey consistency. Quite a number of springs make their appearance between the Medina and this blue clay layer. Underneath is the horizon of the Cincinnati group.

II. *The J. V. D. Smart sections*, including part of the former Charles Dalyrymple farm. Going from the center of Belfast south to the bridge, westward to the exposure of the basal Clinton, bending towards the southwest about a quarter of a mile, and then taking a road at a right angle to the latter, that is going northwestward, two sets of exposures are found before the abrupt turn of the road to the westward is reached, one of these, about half way along the northwest stretch of road, the other near its northern end. The first of these exposures (locality 13) is along a small streamlet, running only in wet weather; it is only a short distance east of the road. The uppermost layers are cross-bedded, and overlie a conglomeritic layer 12 inches thick, with many flat pebbles, some of which were four to six inches in diameter, and did not show signs of fossils. Farther northward at the second locality (locality 14) the conglomerate is exposed in the road bed. Here one of the pebbles, of whitish sandy limestone, stained brownish by iron compounds where weathered, contained a young Rhynchonella, which is probably Rh. scobina, and about half a dozen valves of Rhynchonella

acinus var. convexa, the large Clinton form found also in the upper or ferruginous Clinton in the Sharpsville section. This showed that the pebbles were of Clinton and not of Cincinnati age, as hitherto stated. The lithological character of the various pebbles was similar to the various Clinton layers known in this vicinity, but not to any known Cincinnati rock. Eastward from this road bed exposure the conglomerate is well exposed along a more northerly situated streamlet, running, as did the last, only in wet weather (locality 15). There is evidently an upper horizon of the Clinton, scarcely more than 15 inches thick, which is full of pebbles. Many of these are eight to ten inches in diameter. The pebbles are always very flat, and rarely contain fossils. They evidently are chiefly derived from the stratified, more sandy looking Clinton layers, which characterize the lower half of the Clinton, but which are also found very far up in the series. At the present locality, this sandy stratified rock forms a layer immediately above the conglomerate layer, and is abundantly shown in the remainder of the section on following the stream eastward. Both of the streams mentioned flow eastward, and join before emptying into the main fork of Brush creek. The base of the Clinton, with its underlying Medina, is well shown a little east of this junction, on the north side of the stream (locality 16). The top layer showed one of the annelid teeth characteristic of this horizon. Following the hill-side along the western side of the open valley, the fine road-side exposure of the base of the Clinton, to which reference has already been made, is seen (locality 17). It is on the land of J. V. D. Smart, on the north side of the road leading from Belfast to Fairfax, and not far west of the bridge over the fork of Brush creek southwest of Belfast. At the top, 12 inches of the sandy looking limestone were shown. Underneath were four inches of chert; this was the chert layer seen on the eastern side of the creek in the Wm. Haigh section. Below were 26 inches of massive limestone with cherty nodules and also with cherty bands along the vertical crevices of the rock, showing the secondary nature of this chert. Then, 20 inches of shelly limestone, meaning by this

a limestone that weathers into fragments one inch or slightly more in thickness, and four to six inches in length, tapering out more or less towards the edges, so as to totally destroy its value as a building stone. This limestone also contained siliceous and cherty nodules, and was in itself quite siliceous. Below this were 24 inches of poor shaly limestone, under which the so-called Medina made its appearance. Following the steep hill-sides along the southern side of this fork of Brush creek, eastward from this exposure, the basal portions of the Clinton and the underlying Medina are well shown as far east as the next bridge, where the pike from Belfast to Loudon and Locust Grove crosses the fork.

III. *Bridge exposure.*—Along the pike leading from Belfast to Locust Grove, the locality mentioned just above (locality 18). Here the so-called Medina is well exposed; it is quarried, and is considered an excellent building stone. It will be remembered that it was quarried also at Arment's quarry in the bed of Turtle creek, in the Sharpsville section. The top layers of the Medina here contained a considerable number of annelid teeth, and also a single but good specimen of Halysites catenulatus.

Returning to Belfast from this bridge, the Clinton limestone is exposed on the side of the road, on the north side of the main valley formed by the fork (locality 19). The section on the Smart farm could be readily measured with proper instruments. The conglomerate layer is evidently nearly at the summit of the Clinton. Estimates made by eye alone would hardly give the Clinton here a greater thickness than 35 feet.

Elk Run.—Going north from Belfast, take the first road going east; two miles from Belfast the road crosses Elk Run, across an iron bridge. In the bed of the creek the top of the Clinton is shown (locality 20). At the top are 20 inches of ferruginous Clinton, showing cross-bedding, and a few pebbles. Near the middle they contain also a thin layer of blue clay. If the memory is not at fault similar thin blue-clay layers are seen near the top of the Clinton in the Wm. Haigh section. The fact was not recorded at the time of observation. The fossils

found in this ferruginous rock (which included both sandy and oölitic layers) were Platyceras (Platystoma) Niagarense, the small Soldiers' Home form, Leptæna rhomboidalis, Orthis elegantula, and good specimens of Aspidopora parmula. By far the most interesting feature of the locality however was the presence of great wave marks, wonderfully distinct and well exposed for a distance of a hundred feet down the creek. The line of strike of these wave marks was magnetically about north 65° east. The crests of the wave marks were about two inches above their greatest depressions, and the distance from one crest to the next was on the average about 28 inches. They sloped northwards a little more steeply than southwards. This wave-marked layer is only from one to two inches in thickness, and immediately overlies a great mass of pebbles, imbedded in the Clinton just beneath. These pebbles sometimes project strongly into the sandy layer above, which shows the wave marks. The pebbles are on the average larger than at any place where pebbles have so far been seen in the Clinton. Plenty of them are 12 inches in diameter, and many of them range between four and eight inches. As usual, the pebbles are only an inch to an inch and a half in thickness. Lithologically they are similar to the sandy stratified layers of the Clinton limestone, found characteristically in the lower half of the Clinton in this part of the state, and occurring also at higher levels. If there had been any doubt hitherto about the Clinton age of these pebbles, it was dispelled by the fossils found in some of the pebbles at this locality. The pebbles here were again almost invariably unfossiliferous, but there were so many pebbles in the rock, and the conglomerate layer was so well exposed, that it was possible to break out enough pebbles in a short time to make a satisfactory examination. Three of the pebbles contained fossils. The forms found were Illænus daytonensis, fragment of a glabella, a rostrum probably belonging here, and a very good pygidium; Cyphaspis clintonensis, the middle parts of two heads in a very good condition; half a dozen specimens of a small form of Orthis elegantula, and a young Rhynchonella, probably Rh. scobina.

The first two species named clearly identify the rock from which these pebbles were derived as Clinton, a fact already manifest from a consideration of the lithological features of the pebbles, to those thoroughly acquainted with the Clinton.

Ellenville section.—Ellenville lies about four and a half miles east of Belfast, farther on along the same road which leads to the Elk Run section. In loose boulders of the Clinton good specimens of Strophomena patenta, Aspidopora parmula and other characteristic Clinton fossils were seen. The section here described begins about half a mile south of Ellenville, along the east side of the pike, where the Dayton limestone of excellent quality with courses 12 inches and more in thickness is exposed at several localities, usually east of the culverts where streamlets cross the pike (localities 21 and 22). Underneath the Dayton limestone is found the deep red sandy Clinton, and below this the ferruginous and at times oölitic Clinton, but no pebbles were seen. About a mile south of Ellenville after crossing a somewhat larger culvert, and where the pike ascends a somewhat steep hill, the Dayton limestone is exposed in the woods (locality 23) at some distance east of the pike and at a fair elevation. Tracing it eastward, it seems to rise in altitude. Along the pike (locality 24) the Clinton is well exposed. It is often well cross-bedded and in different directions. Ascending the hill, quite a thickness is well shown. Reaching the top of the hill, a little streamlet, descending rapidly to the middle fork of Brush creek, again well displays the Middle and Upper Clinton (locality 25). It is deeply red in color, of a sandy type, and frequently cross-bedded, but does not show, where examined, any pebbles. At the creek, a short distance below the point of entrance of the little streamlet just mentioned, the base of the Clinton is well exposed (locality 26). About eight feet of the Clinton are seen, containing cherty concretions in nodules and along vertical cracks, and showing the so-called shelly layers mentioned in connection with the Smart section near Belfast, and also some very siliceous but not exactly cherty layers. Meristella umbonata was found here.

Peebles Station.—About 10 miles southeast of Belfast, and 44 miles southeast of the Todd's Fork locality.

Following the Cincinnati, Portsmouth & Virginia railroad westward from Peebles, a high trestle is crossed, west of which the Niagara shales are well exposed. Still farther westward, about two miles from Peebles station, there is a small house on the south side of the railroad (locality 30). It is on the land of Tom Gardner. The farm line runs a short distance east of the house, and east of the line is the farm of James Philips. Along the railroad, 300 feet west of the house, the Dayton limestone is well exposed (locality 31). In the middle courses of this Pentamerus oblongus is found. In the report of the Ohio Geological Survey for 1870, page 280, the following statement is found: "Col. James Greer, of Dayton, has in his cabinet a specimen obtained from the Dayton stone, the lowest member of the Niagara series, which is probably Pentamerus oblongus, in somewhat abnormal form." The present is as far as known the first instance in which the occurrence of the Pentamerus in the Dayton limestone is authenticated by its reference to a locality where the rock is evidently *in situ.* So far no lower horizon for this fossil in Ohio is known. It is additionally interesting for presenting the original shell, although the shell usually splits away and leaves the cast, when an attempt is made to work it out. The Dayton limestone is also exposed some distance east of here, on the Philips farm (locality 28), in the bed of the creek which follows the railroad on its southern side. Here slabs sometimes contain Pentamerus in abundance. The Clinton is well exposed beneath. The upper portions are ferruginous, either sandy and stratified, or at times oölitic. At one point it seemed possible to trace a sort of wave-marking running north 40° west. In the light of later discoveries in the Cincinnati, these traces may have some value, though in themselves unsatisfactory. In the sandy layers the stratification is sometimes well marked. The Clinton is made up of very different courses, some of them sandy and red, others oölitic, crinoidal and deep red, and still others of very pure limestone and white. A course

of the last kind is seen a short distance east of the farm line mentioned (locality 29), and is very rich in fossils. Down the stream, across the line, behind the house (locality 30), the Clinton bowlders show the nearest approach to pebbles seen in this section. Strongly rounded specimens of Favosites, Heliolites, and Cyathophyllum are quite common here and are also found farther up stream. Behind the house some specimens do not show structure but may possibly have been strongly rounded stromatoporoid sponges. It would require microscopic sections to determine the matter. Farther down stream the reddish color disappears, and where the creek passes under a bridge to the north side of the railroad the west embankment of the bridge (locality 32) exposes 8 feet of the basal part of the Clinton. It has a very irregular structure, similar to that called shelly above, is very siliceous, and contains nodules of chert. The piers of the bridge on this side were constructed by going down into the bottom of the creek bed, and there Cincinnati rock was struck, showing well-known Cincinnati fossils in abundance. At the top, the thin Cincinnati limestone fragments show a thin coating of a shaly material, in which annelid teeth are found. The total section of the Clinton is therefore shown along this stream. It hardly exceeds 30 feet, as determined by estimates made without the assistance of instruments. The top layer of the Cincinnati group shows abundant encrinital remains, and numerous specimens of a small Tentaculites. Leptæna sericea is common. The following species were observed in the Clinton, chiefly in its upper courses, though the middle courses are in places rich in fossils; but the latter were not examined: Illænus ambiguus, pygidium in the Lower Clinton; Calymene vogdesi, both of large and medium size; Cyclonema bilix, Leptæna rhomboidalis, Strophomena patenta, Orthis calligramma var. eu-orthis, Orthis biforata var. reversata and var. daytonensis, the latter with only three plications on the median fold; Orthis elegantula, Rhynchonella scobina, Clathropora frondosa, Phænopora, a long simple frond 10 mm. broad at the top, species unknown, Aspidopora parmula, very common in the richly fossiliferous layer

east of the farm line, Heliolites sub-tubulatus, and Halysites catenulatus.

REMARKS ON SOME FORMATIONS ABOVE THE CLINTON.

Observations by the Kentucky Survey.—The *Niagara shale* seems to become thinner southward and westward in Kentucky, as far as can be determined from the statements that it is 100 feet thick in Lewis, Fleming, and Bath counties, 35 feet in Marion and Nelson, and 15 feet in Oldham, being sometimes entirely absent in the last county. It varies greatly in thickness. It is not mentioned from the most southern counties, but this may be partly owing to the difficulty in discriminating between the Niagara and the Crab Orchard shales in that region.

The *heavy beds of the Niagara* are seen in Pickaway county, Ohio, and extended thence as far as Highland county of that state. In Kentucky, judging from residuary fragments left on the bedded rocks, the eastern line of outcrop once extended from Bracken county to Nelson and part of Washington counties. Continuing in the same southwesterly direction it passed into western Tennessee. West of the line thus located, the heavy beds seem to have covered all the areas within the present regions of suitable outcrops in the states of Ohio, Indiana, Kentucky, and Tennessee. The beds therefore do not occur between Adams county, Ohio, and Washington county, Kentucky, the eastern and southern range of counties.

The *Oriskany*, on the contrary, occurs only in these counties, from which the heavy Niagara beds are absent, that is in the counties from Lincoln to Bath. It usually is a single layer 12 to 18 inches thick, but in Bath is three feet thick. It usually contains fish remains, which are often much rolled and rounded.

The *Corniferous* occurs west of a line which lies so much farther east than the line of outcrop described for the heavy beds of the Niagara, that it practically occurs at all suitable exposures in Ohio, Indiana, and Kentucky, and is absent only in the extreme east, in Adams and Lewis counties, the Ohio river counties of Ohio and Kentucky.

The *black slate* covered all regions of Kentucky where proper horizons are exposed at present.

Mention has already been made of the iron pebbles just beneath the heavy beds of the Niagara in western Washington county, and of the rounded grains of quartz above the Crab Orchard shale in Garrard county. In the geology of Lincoln county the statement is made that in nearly all the layers of the Upper Silurian and Devonian, and even in the base of the black slate, there are small transparent grains of quartz. These are nearly microscopic but they are well rounded. In the black slate they are mentioned from Nelson, Lincoln, Garrard and Clark counties. Wave marks occur in the black slate in Lincoln county and also in Clark county, near the base.

Unconformities.—In southern Clinton county and adjacent Tennessee the black slate rests directly upon the Hudson River rocks. In the northern parts of the county, and in Cumberland county, it rests upon the Cumberland sandstone. In Lincoln county both the Corniferous and the Oriskany appear below the black slate, but the Oriskany rests sometimes upon the Crab Orchard shale and sometimes on the Medina ; at one point a little Niagara limestone seems to come in above the Crab Orchard shale. In Marion county the Corniferous rests directly upon the Crab Orchard shales. In Garrard county the Corniferous frequently rests directly upon the Crab Orchard shale, but sometimes the limestone layer with rounded quartz grains, already mentioned, possibly Oriskany, intervenes. In Clark county the Oriskany is well recognized, and rests on the Niagara shale. All this is in keeping with the other facts already mentioned, in accordance with which the sandy, detrital elements increase in the Lower Silurian, in the Cumberland sandstone, in the Medina, the Crab Orchard shales, and various later rocks, on going southward.

As already stated, the heavy beds of the Niagara are absent in the southern and eastern counties of Kentucky. Going northeastward the Oriskany disappears near the middle of Bath, and the Corniferous in Fleming county. They do not appear again until Highland county, Ohio, is reached.

Observations made by the Ohio Survey and the writer. Springfield limestone.—Peebles station, about 10 miles southeast of Belfast, and 44 miles southeast of the Todd's Fork locality, on the Cincinnati, Portsmouth & Virginia railroad. Along the railroad about a quarter of a mile west of Peebles, where the railroad crosses a creek (locality 27), there are very good wave marks in the rock on the north side of the railroad, in a sort of quarry. The rock is of a bluish tint, and is some distance above the Niagara shales. It is presumably of the Springfield horizon. The crests of the waves run here north 3° east; they are about 3½ inches above the troughs of the waves, and are about 42 inches apart, showing therefore approximately the same characteristics as the waves of Clinton age in Elk Run. They descend more rapidly eastward than westward. The wave marks are seen at several levels through a thickness of 2½ feet of rock. Under the wave-marked courses is one marked by crossing ripples, on an equally large scale, such marks as can be seen on the seashore where the ripples from various directions cross each other and break up the regular wave markings. Just below, little pebbles, a quarter of an inch to one inch in diameter, occur at the base of the wave-marked beds. Their color now is gray, the surrounding material being blue. Otherwise they could hardly have been recognized. They are therefore not satisfactory pebbles. Where the railroad crosses the creek, 50 feet towards the southeast, the wave marks are shown over a larger area. The crests here run north 5° west.

Waterlime.—Ripple marks and suncracks are found in the Waterlime or Helderberg in Champaign county, and are used at Urbana for sidewalks. Suncracks occur in Fayette county near Washington, and also near the southeastern part of the county. At Rockville some of the courses are covered with suncracks and ripple marks. Indications of shallow waters occur also in Highland, Pike and Adams counties, according to Professor Orton (page 292, Report for 1870, Ohio).

Corniferous.—In Marion and Delaware counties, at the junction of the Waterlime and the Corniferous, the latter is largely

composed, locally, of rolled pebbles of the Waterlime. Many floated fragments of land plants, including branches of Lepidodendra, have been found in the Corniferous at Delaware and Sandusky, showing the proximity of land.

Hillsboro Sandstone of Highland county.—Professor Orton, in the 1870 report, page 283, wrote: "The only remaining division of this extensive series (Niagara) of rocks is the Hillsboro sandstone, the sixth member of the Niagara group in Highland county. . . . It is a unique and original contribution of Highland county to the general geological scale. Limestones and calcareous shales constitute the only kind of rocks that have been referred to this period hitherto, in the Mississippi Valley; *but at Hillsboro and on the eastern border of the county generally*, a siliceous sandstone of a good degree of purity is found terminating the series. . . . The thickness of this sandstone at Lilley's Hill (at Hillsboro) is 30 feet, and no greater thickness is shown elsewhere. The sand that makes up the rock is fine-grained and but slightly cemented."

GENERAL CONCLUSIONS.

A brief résumé of the more important facts regarding the geographical distribution of wave marks and pebbles.—In the Trenton of Kentucky the wave marks and pebbles are mentioned only from the southeastern counties of the Blue Grass region, Garrard, Clark and Montgomery. The pebbles occur near the top.

In the Utica or "Lower Hudson," rounded limestone pebbles occur in the lowest bed in Washington county, and apparently also in Mercer, Boyle, Clark and Montgomery counties. These are again the southern counties, and lie in about the same set as those mentioned as containing pebbles in the Trenton. The occurrence of pebbles at West Covington, opposite Cincinnati, and the widespread distribution of wave marks wherever the upper strata of the Lower Hudson are exposed (the list of counties completely encircling the Blue Grass region of Kentucky) point to a more widespread exposure to wave action.

In the Middle Hudson wave marks are mentioned from near

the base in Washington county; also from Nelson county, both southwestern counties of the Blue Grass region. Their occurrence in Nelson county seems to be extremely doubtful. At the top of the Middle Hudson, and the base of the Upper Hudson, are arenaceous elements which increase in thickness and coarseness going southwards.

In the Upper Hudson wave marks appear in Oldham, Lincoln, Clark, Montgomery and Fleming counties of Kentucky and in Adams county in Ohio. Pebbles occur in Clark and Montgomery counties in Kentucky, and in Adams county in Ohio. With the exception of Oldham, these are the eastern counties in Kentucky and the southeastern ones of Ohio, in the Lower Silurian region.

At the top of the Lower Silurian comes in the Cumberland sandstone, which has its most marked development in the southern counties of Kentucky.

The Oneida conglomerate is barely represented in Boyle, one of the southern counties of Kentucky.

In the Medina, wave marks have been noticed only in one county, Lincoln, the most southern county of this region, and just southeast of Boyle. The Medina seems to increase in thickness southeastward in the eastern range of counties.

In the Clinton, wave marks occur in Montgomery, Bath, Fleming and Lewis counties, Kentucky, and in Adams and Highland counties in Ohio. These are the most eastern of the Clinton group counties. [It is approximately the same area over which, later, the Corniferous failed to extend. On approaching this area, the Oriskany of Kentucky thins out; it is a part of the eastern set of counties over which the massive limestones of the Niagara fail to appear.] The oölitic iron ore has a somewhat great extension, being apparently present in Garrard, and certainly in all the counties from Clark in Kentucky to Clinton county in Ohio. The Crab Orchard shales, which represent the Clinton in the southern counties, thicken going southward. Farther north they form only the lower part of the Clinton, and merge into the lower sandy limestone of this group. This

lower more sandy Clinton also thickens eastward. Pebbles were found in the Clinton only in Ohio, in Clinton and Highland counties, being more frequent in the latter.

Location of shallow waters as evidenced by pebbles and to a certain extent by wave marks.—In the late Trenton and early Utica or "Lower Hudson," shallow waters, as evidenced by pebbles and wave marks, occurred over the southern Blue Grass counties of Kentucky. In the late Utica, shallow water areas extended over the entire Blue Grass region of Kentucky as far as the Ohio side of this area near Cincinnati. In the early Middle Hudson shallow waters are again confined apparently to the southern counties, while towards the middle and close of the Upper Hudson, with the exception of Oldham county, the shallow water areas extended all along the eastern counties from the most southern one, Lincoln, as far as the most northern one, Adams, in Ohio. This location of shallow water areas in the eastern counties, instead of over the entire Blue Grass region during Upper Hudson times, will, if substantiated by future investigations, be very suggestive as to geographical changes during pre-Clinton times.

In the Oneida and Medina shallow waters again occurred in southern counties. But in the Clinton it is again the eastern counties, all the way from Clark in Kentucky to Adams in Ohio, which give the evidences of shallow waters.

In the rocks here discussed two kinds of materials occur—fossils or their comminuted remains, derived from the animal life of the Palæozoic seas of these regions, and detrital materials of a foreign nature, derived more or less directly from some land area. The detrital beds usually increase in thickness going southwards, and not infrequently also, though apparently to a less marked degree, on going eastward. The explanation for this may be that land lay in these two directions, but an equally suggestive way of stating what perhaps amounts to the same thing, is that these detrital remains may have been carried northward and westward by some ocean current which found its way northward along the eastern border of some Palæozoic continental area.

Conclusions to be drawn from wave marks and pebbles.—No one who is familiar with wave marks as made along long surf-beaten beaches of the ocean, can doubt for a moment the origin of the wave marks. Their unusual size will, however, attract attention even from one familiar with the work of the sea. Yet it must be remembered that we are familiar only with the wave marks left by the edge of the sea, where the force of the waters has been almost spent. It is readily conceivable that farther from the shore different results, at least as regards magnitude of wave marks, might be expected. It has always been a hope of the writer to, some time, be able to photograph the bottom of the sea after some great storm, along some exposed coast, with good sand bottom. This could readily be done by a camera properly constructed, using electric light as a means of illumination.

The magnitude of the wave marks here referred to would indicate free exposure to the sea, but would not determine much as to its depth. The writer does not know of large wave marks at great depths. On the contrary the largest he ever saw were at the mouth of Hampton river, in Massachusetts, considerably above low water mark. These fully equaled the wave marks of the Ohio rocks.

As regards the pebbles, all the evidence in the case of those found in the upper Utica, in the "Upper Hudson" and in the Clinton is to the effect that they were derived from practically the same beds as those in which they are now found imbedded. To be more precise, their lithological character and the contained fossils are always those of rocks belonging to the same bed in which they are now found or at best only a few feet farther down, but not sufficiently beneath to suggest their origin from a separate palæontological horizon, even on the basis of the most careful classification. Evidently the waters were shallow enough to permit erosion. This may have occurred without actual elevation of the rock above sea level, but it is more natural to suppose that such elevation above sea level did take place, that the land area was but slightly elevated and was soon again submerged, leaving the irregularly eroded surface a

play to the waves. If the association of wave marks with these pebble areas be remembered, it will be readily understood that the forces capable of leaving these marks could lift up the loosened slabs of Cincinnati group and Clinton rocks, round them more or less, according to their constitution, size, and length of time of exposure, and redeposit them as pebbles over some other area not far distant, where the same layer might have been less exposed or but little affected—in other words, a little farther seaward.

While, therefore, it is probable that shallow waters extended at various times over more or less of the Blue Grass region in Kentucky and Ohio, it is at no time probable that land of any great elevation was to be found here in Lower and Middle Silurian times. The land areas which did exist over these regions were always soon covered again by the sea, as far as we can judge from available information.

That land areas may have existed immediately east and south of the Blue Grass counties seems not improbable, but is not certain. The few facts known are not averse to an east and west axis of elevation south of these counties, and another one, running north and south, along the eastern border of the same. The latter axis seems to have been in process of elevation towards the close of the Lower Silurian and again during Clinton times. That this elevation was more marked on both sides of the Ohio river during Clinton times seems to be indicated by the pebbles found in Adams county, and that it increased here in importance by the fact that later the Corniferous rocks failed to appear here; and that still later the Oriskany thinned out on approaching this area.

The failure so far to discover pebbles derived from horizons decidedly below those in which they now occur imbedded, indicates that either the elevation of the land area above sea level was slight, or that it was of such short duration that erosion did not find sufficient time to produce deep river valleys or marked shore escarpments. In the case of a low dome-like elevation, the raised parts exposed to erosion would furnish the pebbles,

and these would be carried by streams or waves to less elevated regions, where they would be deposited over beds which either had not experienced erosion at all or had suffered but slightly. The pebbles would therefore be found overlying the lateral extension of the beds from which they had been derived.

It is still too early to say that marked shore escarpments did not exist. It is sufficient for the present to state that they have so far not been discovered, and that the failure of pebbles from decidedly lower horizons to appear, is decidedly against their former existence. It might be worth while to consider under what conditions such escarpments would be formed, and when they would be preserved. It is evident that during the gradual emergence of land above sea level any small escarpment formed by the sea would, on continued elevation, be exposed to aerial denudation which might accentuate it, but would be more likely to do the opposite. On the depression of the land area below the sea level, the same land surfaces would once more become a prey to the action of the waves. In either case, whether of emergence or depression, escarpments of any size would be formed only during periods when elevation or depression were at a standstill. The height of these escarpments would be determined by the slope of the land surface and the sea bottom leading up to the same, and by the length of time during which the land would admit of attack at practically the same levels. The best escarpments would not be formed during the rise of a land area, when the waters nearer the line of attack upon any shore would gradually grow shallower, but during the depression of the same, when any advantage gained by cutting through several layers of some bedded series of rocks was hardly likely to be lost, as the gradual increase in depth at this point permitted the more violent impact of the waves. Any fairly rapid period of depression would then preserve such an escarpment in good form for the future geologist.

The failure to find evidence of an escarpment may be proof merely that there were no long periods of rest either during the elevation or depression of the land area.

If the elevation of land had been at all considerable, river valleys should sooner or later have been formed of sufficient depth to insure their preservation under the accumulating débris as the land gradually sank under the sea. The upper banks of these rivers would in this process form shores of the sea or inlets, with however a possibility of being less subjected to the brunt of the waves, and hence a better chance for preservation than more exposed shores.

Nothing of the kind has so far been found in the area here studied. Conglomerates have been found, but the age of the pebbles forming the same is rather in favor of but low elevation, so low that even in the Clinton, with its small thickness of thirty-five feet, and its pebbles at times only fifteen to twenty feet above the bottom, no pebbles of Lower Silurian origin have been found. The pebbles, on the contrary, are now found only a very short distance above the horizons to which they originally belonged. This certainly suggests but a low elevation of these Silurian land areas, at least where so far examined.

The point of greatest interest in all these facts lies, therefore, in the evidence of conglomerates over a considerable area, in conjunction with equally clear evidence of their production without the assistance of any marked elevation.

AUG. F. FOERSTE.

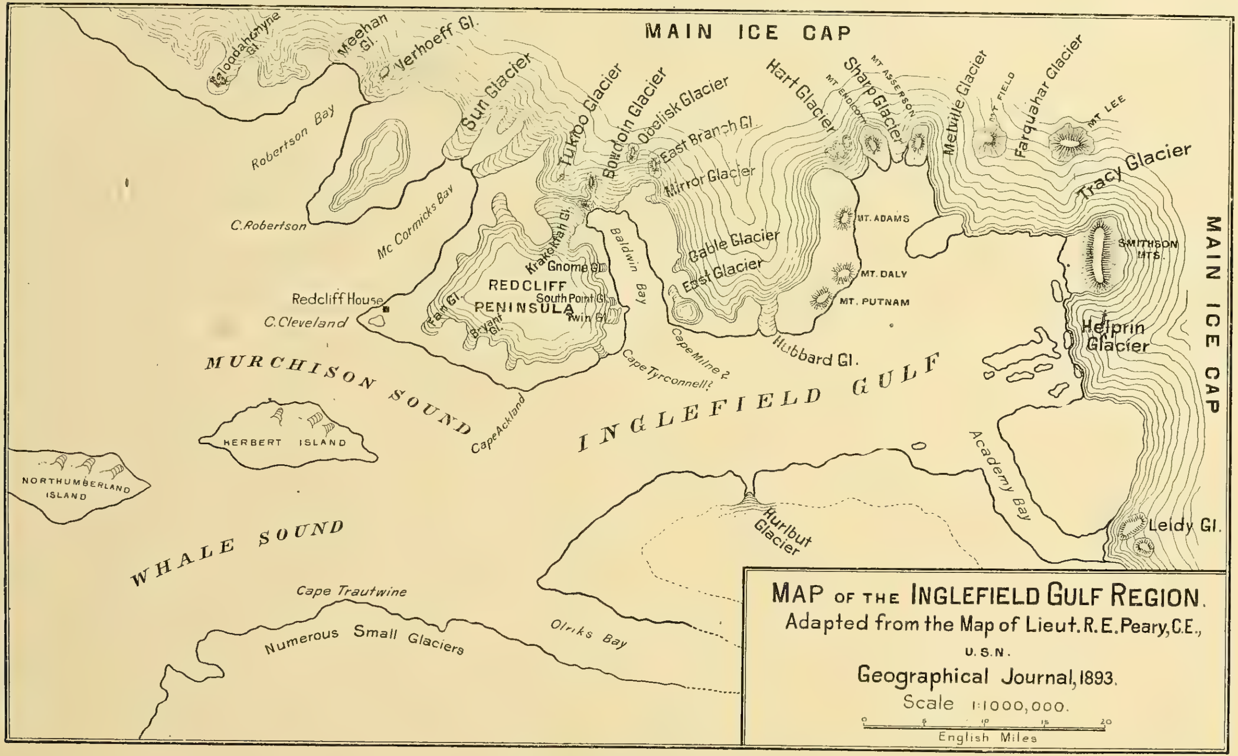
GLACIAL STUDIES IN GREENLAND. IV.

Glaciers of the Inglefield Gulf Region.

General features of the district.—As my chief studies on the glaciers of Greenland lay within the environs of Inglefield Gulf it will be helpful to take a brief survey of the region before entering upon a special description of its glacial phenomena. It is worthy of note at the outset that it is the westernmost portion of Greenland that is indented by Inglefield Gulf. Prudhoe Land, which constitutes the extreme western projection, lies immediately on the north, while next on the south lies the unnamed peninsula which ends in Cape Parry and constitutes the next most westerly portion. The position of the gulf is therefore one of meteorological exposure, if westerly projection constitutes such exposure.

It is equally worthy of note that the district lies on the border of one of the widest parts of Greenland, if not altogether the widest part. With the present incomplete knowledge of the east coast, an unqualified statement is inadmissible. According to some of our maps of the better order, the tract between 77° and 78° north latitude, which embraces Inglefield Gulf, is wider than any similar portion north or south. According to other maps the breadth near 70° north latitude fully equals, or slightly exceeds it. In the former region the tract stretches over more than 50° of longitude. The convergence of the meridians in this high latitude, however, makes this an illusive statement, unless the fact of their close approach be borne in mind, but it serves to emphasize the width of the area in whose glaciation we are interested. In round figures and more familiar measures, the breadth may be put down at about 700 miles.

If we turn from the width of the land to the more pertinent matter of the width of the ice sheet, we find all maps agreeing



MAP OF THE INGLEFIELD GULF REGION.
Adapted from the Map of Lieut. R. E. Peary, C.E., U.S.N.
Geographical Journal, 1893.
Scale 1:1000,000.

that here the ice finds its greatest expanse. The glacial phenomena we are to consider relate, therefore, to the widest part of the widest *mer de glace* of the northern hemisphere.

Inglefield Gulf indents this broad tract to a depth of about 100 miles, or one-seventh of its width. The trend of the gulf is a little north of east. It has a breadth of from eight to twelve miles. There are two notable branches on the north side, McCormick Bay and Bowdoin Bay, both of which have become memorable from their association with Lieutenant Peary's work, the former having been his headquarters during his first exploration, and the latter, during his second. On the south side there are likewise two arms, Olriks Bay and Academy Bay.

General geology.—Two great series of rocks are represented in the district, the one an ancient complex crystalline terrane, probably Archean, the other, a clastic series of unknown age. The crystalline series is chiefly composed of gneisses in which a strong hornblendic tendency is manifest, some parts, indeed, being largely hornblende. There are also embraced in it some belts of quartzite which bear a general resemblance to the quartzites of the Algonkian series of the upper Mississippi and Lake Superior regions.

The clastic series embraces three distinguishable members. The lowest is a red sandstone which attains a thickness of perhaps 1000 to 1500 feet. Its beds possess moderate massiveness, lie at low inclinations, and rest unconformably upon the crystalline series. The discordance is very great and indicates that the crystalline terrane had assumed essentially its present attitude, had undergone very great erosion, and had approached the existing topographic expression before the sandstone series was laid down upon it. If the sandstone were removed, the relief of the topography would apparently not be less than it is now, and not very different from it in general aspect.

Lying conformably upon the red sandstone is a somewhat thicker series of pinkish gray sandstone. This has a quartzose constitution much the same as that below, but somewhat exceeding it in hardness. While well indurated, it is unmetamorphosed.

Under glacial action it manifests its endurance very markedly, and constitutes, in favorable situations, a very notable constituent of the drift. Its thickness is roughly estimated at 1500 to 2000 feet.

Reposing conformably upon the pinkish gray sandstone lies a deep series of more thin-bedded sandstones and shales, of reddish brown and dark hues. The sandstones, which predominate over the shales, are less heavily bedded than the series below. They manifest a marked disposition to split up into thin slabs under exposure, and hence degradation proceeds with much facility. Interstratified with the sandstones there are shaly beds of kindred constitution which were obviously once only the more muddy sands of the accumulating sediments. Besides these sandy shales there is found on the south side of Redcliff Peninsula a very notable horizon of finely leaved shales of dark color, which disintegrate with great readiness into a soft talus of leaflets, extremely grateful to the feet of the explorer after their hard pounding over the rocky or bowldery surfaces that nearly everywhere prevail unsoftened by soil or vegetation. These more pronounced shales do not, however, appear to be sharply differentiated from the common sandstone and shale series, but possibly a more thorough study of the region would find grounds for separation. The thickness of the whole series can only be vaguely estimated from such cursory observations as I was able to make, but I should judge that it exceeds rather than falls below the estimate of the preceding series. No careful measurements of the thickness of any of these series were made, and the figures given are general estimates that will be serviceable only in giving an approximate idea of the massiveness of these formations.

The conformity of the three sandstone series among themselves suggests that there may be no vital distinction between them and that they represent a consecutive sedimentation reaching a total thickness of four or five thousand feet perhaps.

Unfortunately the series is extremely barren of fossils. The absence of these cannot be charged to any catastrophe which the

series has undergone, for, while it is faulted in some places and gently tilted generally, it is not crumpled nor folded and shows no signs of destructive metamorphic changes. While it is by no means safe to assume the entire absence of fossils; while, indeed, it is perhaps safer to assume their presence, they are very rare, or else circumscribed in their distribution within the region studied; for, though attention was chiefly absorbed by the glacial phenomena, it was incidentally necessary to traverse much territory occupied by the sedimentary rocks, and their exposure is so ample as to afford great facilities for observation. Vegetation is not by any means absent, but it is so scattered as to offer practically no concealment of the surface. The intense frost has split the surface beds into innumerable slabs which lie in the greatest profusion over the surface. At the same time there has been very little disintegration of rock into soil, or else it has been washed away, and hence almost no concealment from that source. While in some parts drift from the crystalline series interposes some concealment, the extent of this is limited. The importance of finding a sufficient number of fossils to identify the formations was fully realized and a fairly constant outlook for them was maintained, but without result. All others who have visited the region have been, so far as I can learn, equally unsuccessful. There remain, however, grounds for hope that sufficient fossils will ultimately be found to determine the age of the formations. They have usually been referred, with doubt, to the Tertiary, because of the presence of that series, with a similar constitution, in the Disco region. So far as I can see, they might, with equal plausibility, be referred to an earlier age.

The area occupied by the clastic series is only imperfectly known. The ice mantle of Prudhoe Land and the great inland sheet creep out upon it and conceal its inland limit in part. But such inferences as can be drawn from the constitution of the drift point to a limit at no great distance back from the shore. This is strongly supported by the fact that the arms of Inglefield Gulf reach the crystalline series and even the gulf coast is in part formed by it. The head of Bowdoin Bay, for instance, has crys-

talline walls on either side, though at its mouth there rise picturesque cliffs of sandstone. The Redcliff Peninsula, a triangular area, about fifteen miles on a side, lying between McCormick and Bowdoin Bays (see accompanying map), clearly has a nucleus of crystalline rock. On the south face, the clastic series forms the entire coast line. Each of the glacial tongues, however, that descends from the peninsular ice cap brings crystalline bowlders. As the ice cap is entirely indigenous to the peninsula, and the glacial movement is outwards in all directions, none of the crystalline bowlders can be derived from any outside source. Besides, the nucleus is actually exposed on the northwestern side of Bowdoin Bay. East of Bowdoin Bay the clastic series occupies a narrow tract along the Gulf, while farther back the country is made up of the crystalline series, so far as could be seen directly, or inferred from the drift. On the south side of the Gulf, a part of the coast is formed by crystalline rocks, and a part by the clastic series. At the head of the Gulf, the islands, so far as seen, and the promontories on the south side, are composed of the crystalline series, but the Smithson Mountains (which were, however, only observed at a distance by a field glass) appeared to be formed of pinkish gray sandstone. As they lie in the line of the strike of that formation, it seems not improbable that the old clastic basin extended farther into the mainland than the present basin.

The foregoing observations, taken together, appear to justify the inference that the ancient gulf in which the clastic series was laid down was somewhat more extensive, but not greatly more extensive, than the present one, and that it had approximately the same form, though departing from it in some particulars. It appears also a natural inference that the old basin was the parent of the new one in the sense of having determined its location and measurably its dimensions. It is doubtless an instance of an ancient feature perpetuating itself through later geological ages.

General topography of the region.—The stratigraphy of the district has already led us to a recognition of its greatest topographic feature, the basin itself. A study of its profiles quickly

reveals its second great feature—an upper plane, dominating the higher land and constituting it a very pronounced plateau. We may recall that in a previous sketch of the topography of the coast to the southward, it was observed that though somewhat varying, it takes on a prevailing mountainous character. Indeed, I think that all descriptions of the ice-free belt of West Greenland represent it as mountainous, and these descriptions are fully justified so far as the region south of Melville Bay is concerned. Fortunately a new phase is assumed in this more northerly region.

FIG. 17.—General view of the central portion of the south face of Redcliff Peninsula, introduced here especially to illustrate the non-mountainous plateau upon which the ice cap develops. The ice edge is about 2000 feet above and three miles back from the Gulf. Bryant glacier, at the right, is a typical ice tongue descending from the ice cap through one of the broader and deeper valleys. It will be described in detail farther on. The plateau face is here formed of the sandstone and shale series described above; but the Bryant glacier brings down débris from the pinkish gray sandstone and the crystalline series.

Here we have a pronounced plateau without bordering mountains. The few points about the head of the Gulf that are called mountains rise only a few hundred feet above the plateau, and would be altogether negligible in a really mountainous region. This upper plane lies about 2000 feet above the sea level. Along a portion of the coast there is a precipitous rise from the water to this plane. In other portions, and these have much greater extent,

there is a narrow skirting tract of lower ground, a portion of which is of moderate slope, and often takes the form of a series of imperfect terraces. These, in some places, appear to be merely developments of the talus slope, but in others to constitute remnants of a lower plane of erosion, which has a somewhat wide prevalence, although not an important feature of the general topography of the region. From these lower skirting tracts the ascent to the upper plain is usually steep, though rarely strictly precipitous.

The edge of the plateau is notched by a series of short valleys that lead down from the summit plane. The length of these is not usually more than two or three miles, except in the case of the greater arms, where, if we include the portion occupied by the bays, the length reaches a dozen or even a score miles. At the head of the valleys, the descent from the plateau is usually at first prompt, while towards the mouths of the valleys the gradient becomes lower and is usually determined by the lodgment of gravelly wash from above. The heads of the larger valleys are usually occupied by glaciers. These descend from the plateau into the valleys either by cataracts or by steep slopes. If the glacial tongues do not extend the full length of the valley, as is frequently the case, the lower portion is occupied by a broad plain of gravel and bowlders of glacial derivation, which gives a free and gentle descent to the glacier in its terminal portion. At the junctions of these glacial valleys with the Gulf, there is sometimes a notable delta, broad and symmetrical, but not very large. They do not protrude far into the Gulf even when its waters are not deep The most notable of those observed was the one in front of the Fan glacier. The beautiful fanning out of the glacier at its extremity is reproduced in an almost equally symmetrical deployment of its delta. There are several of the valleys, however, which, though filled nearly to their mouths with glaciers, have no protruding deltas at all. The little embayments at their mouths are not yet filled with glacial wash. This is an observation worthy of note in its bearings upon the duration and activity of the glaciation. The valleys occupied by the Gnome, the South Point, and the East glaciers, may be cited as illustrations.

Returning to the upper plane, it is worthy of note that its undulations are chiefly confined within a range of 500 feet. A panoramic view generally gives a mildly undulatory profile, as may be seen from the accompanying illustrations, and as will be more fully shown in the photographic illustrations that will be hereafter introduced in illustration of the glacial phenomena. Sometimes the profile is very markedly uniform. See Fig. 18. In the immediate district of my studies, there was but one prominence that has been dignified by the name of mountain, Mt. Bartlett, which overhangs Falcon Harbor and the headquarters of Lieutenant Peary, and which receives its characterization chiefly because of the sheer face it presents towards Bowdoin Bay, and because of its close association with the exploring expeditions. Its extreme height is little more than 2600 feet, and its rise above the plateau but a few hundred feet. About the head of the Gulf are several prominences reaching, if I have noted Lieutenant Peary's observations aright, perhaps 3000 feet. They are conspicuous solely because they are promontories. In no instance do these reach the grade of true mountains when referred to the plane of the plateau. Were it extended over the area of the Gulf, all would be reduced to hills of moderate dimensions.

General bearings of the geological and topographic features upon the glacial phenomena.—I have dwelt upon some of the foregoing features, especially the last, because of their bearings upon the behavior of the ice sheet. In drawing inferences from this field and applying them to our own glacial domain, it is obvious that the effects of topography must be eliminated or discounted. In so far as the border of Greenland is roughly mountainous, in so far a disturbing factor is introduced into the deployment of the border of the ice. To this extent it must be presumed to depart from the habit which it would adopt upon the plains of northeastern America. It is scarcely necessary to note that the great drift sheet of our mainland lies for the greater part upon a relatively smooth plain. This indeed becomes rolling, and even to some extent rugged and mountainous at the east, but for the greater part the ancient ice sheet deployed with very great

freedom upon a plain of moderate undulation. It is therefore a matter of much good fortune to find a portion of Greenland upon which the glaciers are now deploying with something of the freedom that the Pleistocene glaciers enjoyed upon the mainland. The outward movement of the ice upon the plateau surface of the Inglefield Gulf region is scarcely less free than upon the average surface of the mainland field. It is, I think, on the whole, more free than the ancient deployment was upon the average surface of New England and the Middle states, though somewhat less free than that upon the average plains of the upper Mississippi and of the great interior of Canada. The interruptions of the movement at the border of the ice consisted almost solely of the effects of the valleys that led down to the Gulf. Into these a portion of the border of the ice sheet crept and stretched forward in tongues from one to three miles long, or in the greater valleys at the head of the bays, a few miles longer. In about half these cases the glacial tongues reached the sea level. In the remainder, they stopped short by distances ranging from a few rods to two or three miles.

The geological structure of Greenland is in general unfavorable to glacial studies. The prevalence of any single formation in a glacial region is infelicitous, because it fails to furnish data for determining the precise locality from which given bowlders have been derived, and hence for ascertaining the courses they have pursued, the rate of wear, and other vital elements of their history. It is especially unfortunate when the formation is one so versatile and deficient of order as the great crystalline complex of Greenland. There is in this case the added misfortune that the débris is chiefly coarse and arenaceous, and hence that characteristic admixture of clay and bowlders which constitutes till, the most typical glacial formation, is generally absent. Not only are the conditions of identification unfavorable, but the conditions for production are adverse.

In the Inglefield Gulf region, however, there is considerable relief from these untoward features. The clastic series contains enough of material reducible to a fine silt to give, under suitable

conditions, a typical bowlder clay, or, if not, at least a distinctive bowldery silt or bowldery sand which clearly stands in its stead. But of much more consequence is the fact that the clastic series forms only a narrow belt along the coast, and that the limits of this, in chosen cases, can be closely determined, so that the extent to which drift has been transported can be approximately learned. From this the intensity of the glacial action may be estimated by a comparison of the amount of abrasion with the distance of transport. Of more consequence than this, even, is the opportunity afforded for observing the position of material of known source in the ice, and hence of judging of the conditions under which the material is introduced into the ice, the method of its introduction, and the course it pursues in the ice. It has been the growing conviction of students of the Pleistocene drift that a large percentage of the material was derived from points not very distant from the places of final deposition. The opportunity to determine how far such local action is the habit of the Greenland glaciers is, therefore, one of the felicitous features of the Inglefield Gulf region.

Glaciers of Northumberland Island.—At the mouth of Inglefield Gulf lie two very considerable islands, Northumberland and Herbert. These present interesting phases of local glaciation that are worthy of a passing word, though it can only be a very general one, as they were merely observed from a distance while the vessel was detained in the vicinity by the ice. On Northumberland Island a considerable ice field accumulates, although its elevation is apparently much short of 3000 feet, and several small glaciers creep down to the vicinity of the sea level. While the plateau surface contributes measurably to the formation of the glaciers, their gathering ground seems to be chiefly in amphitheatres at the heads of valleys, which have developed notable dimensions and taken on the form of circs. Their peculiarity is a circ-like development in the margin of the plateau, combined with an inflow from the plateau surface above. The accumulation of snow is perhaps more due to the lodgment of the wind drift in the amphitheatres than to direct precipitation. In sur-

rounding regions, the heads of the valleys leading from the upper plain down toward the gulf do not usually develop notable circs. From these amphitheatres the glaciers gather into the narrower and lower portion of the valleys and creep down to the vicinity of the sea level. For the greater part they do not actually reach the sea, but stop a little short of it. It is notable that a large part of the drift they have brought down has accumulated at and under their lower extremities, so that they may be said to be creeping out upon causeways, or their feet may be

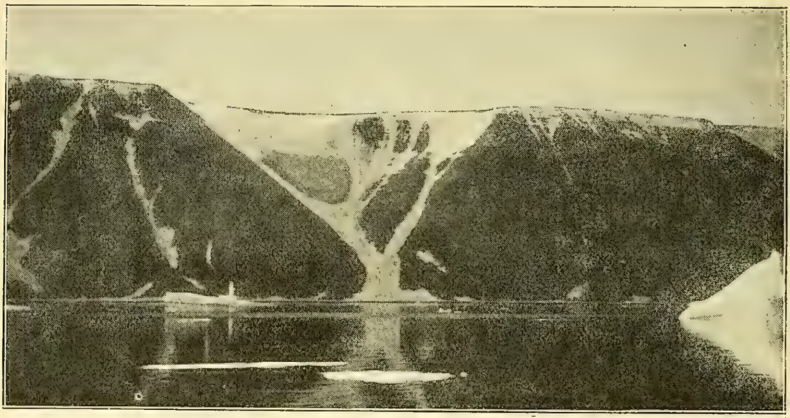


FIG. 18.—Baby Glacier, on the north side of Herbert Island.

said to rest upon pedestals of their own production. Some question might arise as to whether this was not an illusion due to the deceptive appearance of a closely hugging circumvallate moraine, if, fortunately, the glaciers had not in part retired and revealed the terrace-like nature of the pedestal, and if observations elsewhere, to be described later, had not put the verity of the phenomenon beyond question. Professor Libbey quite independently noted the same phenomenon on Herbert Island, and Lieutenant Peary had anticipated us both in remarking it at many places.

Glaciers on Herbert Island.—On the south side and on the west end of Herbert Island glaciers appear to be altogether absent. The valleys leading down from the summit to the water's edge

are free from snow in midsummer, and scattered vegetation makes them the haunt of the reindeer. On the north side, however, there are several diminutive glaciers that are notable for the smallness of their collecting grounds and the steepness of their descents. This is perhaps sufficiently illustrated in the accompanying figure to make description needless. (Fig. 18). This one is so small, so simple, so self-explanatory, as to almost suggest its removal to a museum for illustrative purposes. Small as it is, the fine curvation of its lines of movement is ample

FIG. 19.—Lower portion of the Igloodahomyne Glacier, seen from the southeast.

demonstration of its true glacial nature. The photograph from which the illustration is derived was taken on one of the last days of July, and the melting of August doubtless removed essentially all of the snow that gives the white Y-like snow-figure of the illustration and left still more simplified and expressive the little lobular glacierette, the Baby glacier.

The straightness of the sky line shown in the figure is worthy of note as an indication of the smoothness of the summit plain, which is a part of that previously mentioned as a characteristic of the region. This is too smooth, however, to be quite representative. The glacier here illustrated lies near the western end

of the island. There are some farther to the east which have made a larger growth with a lower inclination. These, like the glaciers of Northumberland Island, terminate on pedestals of their own construction, and of even more characteristic development since the glaciers are narrower and smaller. Here also, fortunately, there has been, in one case in particular and in two or three others subordinately, such a retreat of the ice foot as to leave the pedestal well exposed. One might suppose that glaciers descending so precipitously would plow out their valleys even down to their extremities, but these abandoned pedestals leave no doubt as to their habit under the conditions here presented.

Leaving these little island glaciers, let us cross Murchison Sound and take up the study of a tongue of the great ice cap.

Igloodahomyne glacier.[1]—This glacier lies west of the mouth of Robinson Bay and can scarcely be said to fall within the strict environs of Inglefield Gulf, or even of its northern entrance, Murchison Sound. It belongs rather to the glaciers that cluster about the extreme head of Baffin's Bay. It is a tongue of the ice cap of Prudhoe Land which in turn is a broad peninsular extension of the great interior ice field. The tongue can scarcely be three miles long, and it falls nearly two miles short of reaching the coast line. It is a typical glacial tongue developed on the edge of the ice cap through the influence of the valley which it occupies. It descends from the main ice cap into the valley rather abruptly but without excessive crevassing. Lateral contributions are added in its upper portion, owing to the fact that the valley reaches back into the border of the ice

[1] It is my desire that all the names of glaciers in the environs of Inglefield Gulf which are used in this series of papers shall be credited to Lieutenant Peary. In most cases they are names definitely chosen by him and kindly placed, together with much other valuable data, at my service. In a few cases more than one name had been used or a descriptive phrase employed. It was understood that before we parted a final selection of names would be made, but the multitude of engrossing and diverting subjects that pressed upon our attenion led to its being overlooked. In consultation with Mrs. Peary and Mr. Diebitsch a few names have been chosen to complete the list in accordance with what it is presumed might have been Mr. Peary's choice. The right of nomenclature clearly rests with him.

field. It seemed also to receive small contributions from accumulations of snow on the *edge* of some of the promontories of the upper part of the valley. These were not reached, and the observation may be erroneous, but so far as could be judged by inspection with a glass at a distance of a mile or less, it would appear that large quantities of snow had been accumulated by the wind under the protection of some of the promontories, and that this gradually passed into the form of a subglacier and joined the main tongue. This appeared all the more abnormal because valleys immediately adjacent did not appear to contribute ice streams to the main tongue. There is perhaps nothing abnormal in the phenomenon, however, since it is largely a question of æolian accumulation, and the facilities for lodgment might, under given topographic conditions and special relations to predominant winds, be dependent on promontories rather than valleys.

Below the glacier the valley was found to have a broad, flat, gravelly bottom formed by wash from the glacier. Its ascent between the beach and the foot of the glacier was about 200 feet. No moraine appeared at the end of the glacier. The smooth, gravelly bottom extended uninterruptedly up to the very edge of the ice. This may as well be seen by consulting the accompanying illustrations (Figs. 19 and 21). Not only was this true, but on inspecting the terminus of the glacier no signs of activity were observable. The photographic illustrations will give the reader some suggestion of the inertness that apparently prevails. The edge of the ice may be seen to rest upon the gravelly bottom of the valley with a thin fringe of snowy residue which even in the last days of July and with the southern frontage remains as a representative of the accumulation of the preceding winter, and is still unruptured and undisturbed. On following the border of the ice around to the side of the valley the absence of obvious signs of motion became even more declared. Wash from the adjacent slope had obviously been carried out upon the edge of the ice and had partially buried it, and this had apparently suffered much melting during the preceding season or seasons as well as the current one, but no

clear signs of disturbance by any notable movement of the ice foot was detected. The characteristic humpy surface due to such melting of ice under débris is illustrated in Fig. 20. Here the débris seen in the center foreground is chipstone brought down from the slope on the right. The ice underlies it entirely across the foreground. Farther back and higher up in the left

FIG. 20.—Phenomena on the southeast border of the Igloodahomyne Glacier. The débris from the bluff of sandstone and shale on the right has been washed upon the edge of the ice which has been subsequently melted in part, resulting in a characteristic humpy surface.

central portion of the figure, an inclined belt of lateral morainic material may be seen on the ice slope. Apparently here is the decadence of several seasons undisturbed by any sensible motion of the ice, a state of practical stagnation. It is obvious that the ice border has recently retreated. But this might take place with the ice still creeping on at an appreciable rate and with disturbing effects if the wastage were superior to the advance. It

would appear that though the wastage was very small, the onward movement was so much smaller as to give almost no visible signs of motion at the margin. Some motion is, of course, implied by the very existence of the glacier and its lateral moraines. The absence of appreciable disturbance of any kind is notable because it betrays the sluggishness of the glacial

FIG. 21.—Terminal slope of the Igloodahomyne Glacier; gravel plain and glacial stream in the foreground; alluvial cone and bluffs of sandstone and shale in the background.

activity. So slight was the evidence of motion at the front of the glacier that I was prompted to resort to the closest available method of measurement to determine it—by fixing a stone in the edge of the ice and accurately measuring with a steel tape line the distance from it to a fixed object in front of the glacier—but unfortunately no opportunity to return and make a second measurement was afforded.

The terminal slope of the glacier was steep but not vertical. In some portions it curved rapidly downward to the base, but for the larger part it dropped away somewhat suddenly from a point well up on the brow, the descent being a nearly plane slope, at some points even slightly concave. Along a portion of the face there had been some undermelting, giving an approach to verticality (see Fig. 19). These terminal features place the Igloodahomyne glacier in a class between the Disco glaciers and the majority of the glaciers of the Inglefield Gulf region presently to be described. The Figures 19 and 21 illustrate some of the forms of the terminal slope.

The transverse profile of the glacier, as seen from the valley below, is a quite flat curve, as may be inferred from Fig. 19, the point of view of which is oblique and too near, or still better from Fig. 5 in the introductory narrative, the point of view of which is more distant and more nearly central, although still east of the center of the valley. There is, as will be observed, little débris on the surface of the glacier except near the side.

Ascending to the back of the glacier, which was accomplished without difficulty from the side, there was found to be considerable débris in the lower part of the ice at its lateral edge, but this disappeared as the upper surface was reached. Farther up the valley, on the east side, a very considerable lateral moraine was observed.

The ice was found to be solid and almost free from crevasses on the eastern side, though here and there fissures gaping a few inches were crossed. On the western side crevasses of a few feet in breadth were somewhat frequent over a tract adjacent to a convex border, to the stretching of which they may doubtless be attributed. These crevasses were old and snow-filled for the greater part. Only here and there were there indications of freshly opened fissures, and these were to be measured rather by inches than by feet.

Although it was then a month past the summer solstice, the surface of the glacier was still partially covered with the snows of the preceding winter and spring. Remnants occurred at

almost all elevations, and from a height of 1500 feet upward snow spread over the larger portion of the surface of the glacier; large depressions had indeed been made in it by the heat of the sun, and here and there it was completely removed. Occasional snows fell during the latter part of August and permanent snow was to be expected in September. The amount of surface wastage which the season permitted could not, therefore, be very great, and the inactivity of the glacial mass, as shown by its

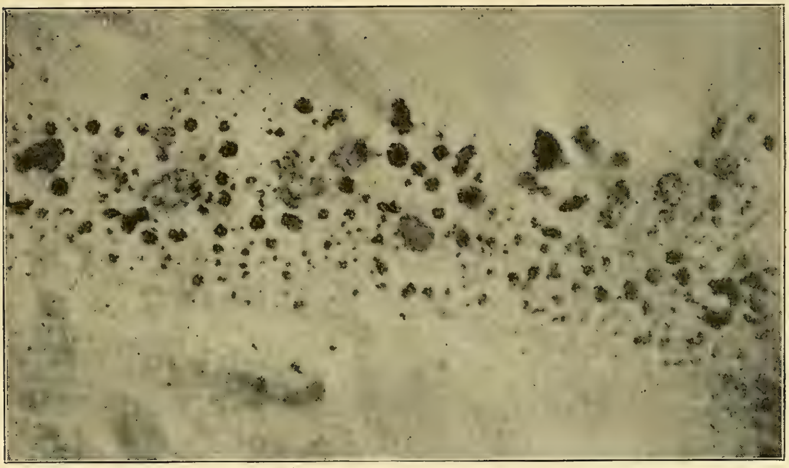


FIG. 22.—Dust wells on the Igloodahomyne Glacier; taken with the camera held directly above them. The largest are about two inches in diameter.

border, is in signal harmony with this limited wastage, which is the factor over against which its motion balanced in determining the status of the mass. It would appear that the wastage is as notably slight as the motion. It is doubtless unsafe, however, to urge these considerations very far, because the season was probably unusually adverse.

At the time of our visit the melting of the surface was markedly rapid, and swift little rills streamed down the slopes of the glacier in miniature channels cut in its surface. The relative absence of crevassing permitted these to run long courses, and by joining each other to form considerable streamlets near the

ends or sides of the glacier from which they plunged downwards in beautiful little cascades.

Perhaps the most interesting feature of the surface of the glacier was its numerous dust wells, a phenomenon which Nordenskjöld brought pointedly to public attention some years since. Upon this glacier they were relatively small but exceedingly numerous and widely distributed. They are cylindrical tubes penetrating the ice to a depth of six or eight inches, or occasionally a little more. They ranged in size from tubelets which would scarcely more than admit a lead pencil up to wells of a foot or more in diameter, though the latter sizes were rather rare. Occasionally they were double or complex, due perhaps in part to the joining of two or more smaller tubes, and in part to original irregularity in the distribution of the dust which formed them. Sometimes there was a central column of ice reaching from the bottom to a capping above which implies the former explanation. The tubes were singularly vertical. Nowhere were they observed to incline to the northward, as holes melted in the snow in southern latitudes so commonly do. There was, however, no question as to their being the effects of melting. At the bottom of each was a thin film of black dust which was their obvious cause. This dust, catching the sunlight and transforming its energy, melted its way downward. The circular course of the sun doubtless tended to correct any tendency to inclination, but even in this latitude the difference between the heat of the southerly and the northerly sun is quite pronounced, and the verticality is apparently independent of the inclination of the sun's rays.

It was noticed that a film of ice frequently stretched across the upper part of these wells, and that the water within them had shrunk away two or three inches from the film. Occasionally there was a second film of two or three inches below the first, and the water had sometimes shrunk away from this also. Obviously the well had been nearly full when the first film of ice was formed, for the most of them were near the mouth of the well. As these observations were made near midday, the sug-

gestion that sprang from the phenomenon was that the film of ice had frozen during the preceding night, and that the falling away of the water beneath represented the amount of absorption of the glacier in the interval, say ten or twelve hours. The significance of this as indicating the facility with which a glacier drinks up water on the surface became obvious, and the desirability of making direct observations upon the wells to determine this was fully appreciated, but the demands of other lines of work and the distance from headquarters of wells suitable for the observations, rendered this impracticable. In another way, however, the suggestions of the phenomenon were in a measure verified. It was observed that whenever thawing was checked by cold weather, it was quite promptly followed by the entire disappearance of the water from the wells. On my first visit to the main ice cap, northeast of Bowdoin Bay, August 7, the surface was saturated with water and the wells were full. On my second visit, on August 10, water was observed only in the ravines into which it had gathered from considerable areas. The surface was then covered with six inches of fresh snow, and special search was not made to determine the presence or absence of water in the wells and the observation was unsatisfactory. On my third visit, August 18, very diligent search was made and no water whatever found in even the largest and deepest of the wells, and these were here of considerable dimensions. It therefore appeared quite certain that the water that was melted upon the surface was absorbed with considerable rapidity into the glacier. Doubtless this descends into its depths. The percentage of the product of melting that is thus absorbed and the rapidity with which it descends into the greater depths are certainly matters of much interest and obviously invite investigation.

The dust in the wells is quite certainly of terrestrial origin, in the main, at least. In some instances fragments of shale were discernible with the naked eye.

The drainage of the Igloodahomyne glacier presents a departure from the method prevalent in Alpine glaciers, though it is

the common habit of this region. The familiar central tunnel, or main drainage line near the middle of the valley was absent, and only little streamlets flowed away from this portion of the glacier. These were very largely formed from the streamlets of the surface which came cascading down the terminal face. No large amount of water appeared to be coming from beneath the base, and this was not murky from glacial silt, as is the manner of streams issuing from beneath active glaciers. The main drainage from the glacier flowed along its two sides. At its extremity these lateral streams followed down the borders of the frontal plain, or turned obliquely out toward the center, branching meanwhile freely, and at length usually came together some distance below the end of the glacier. These lateral streams were murky with silt, but whether it was chiefly due to their tumultuous descent over the lateral débris, or to subglacial grindings, it was not easy to determine. There was doubtless something of both.

The valley occupied in part by the Igloodahomyne glacier afforded an interesting opportunity for comparing the relative rates of meteoric degradation and glacial erosion, though beyond a doubt the comparison is very unfair to the glacier, for here its power was at an extreme minimum, while the steep faces of the adjacent bluffs and the very effective frost action intensified the meteoric agencies of degradation to nearly their maximum efficiency. It was none the less interesting to observe that on the sides of the valley very large and symmetrical alluvial cones were formed at the foot of ravines leading up to the summit plateau. The valley below the glacier retained very little sign of previous glacial occupancy. (See background of Fig. 21.) Attention has already been called to the spreading of one of these alluvial cones out upon the edge of the glacier. A comparison between the facility with which these alluvial cones were formed, and the rate of glacial corrasion, was here at least altogether unfavorable to the latter. But, as remarked before, this is taking the glacier at the greatest disadvantage.

T. C. Chamberlin.

EDITORIAL.

At the close of the recent International Congress of Geologists in Switzerland an elaborate excursion was organized, as is well known, under the leadership of Dr. Albrecht Penck, of the University of Vienna, Dr. Eduard Brückner, of the University of Berne, and Dr. Léon Du Pasquier, of Neuchatel, the purpose of which was to inspect the most instructive sections of the glacial system of the Alps. The appointments are reported to have been most admirable and carried into execution with rare success. Very unusual opportunities were afforded for examining representative deposits and for comparisons of phenomena on both sides of the Alps. At the close a letter very significant of the impressions formed was addressed by the twenty-nine members of the party then present to Dr. James Geikie, reciting that as members of the Glacialists' Excursion they had studied the superposition of three successive glaciations and their interglacial deposits on both sides of the Alps, and desired to address their congratulations to the author of *The Great Ice Age* and to express their regret that he was unable to be one of their party and see for himself a series of exposures which would have had a very special interest for him. The signers embraced Albrecht Penck, Eduard Brückner, André Delebecque, Léon Du Pasquier, Hugh Robert Mill, London; Andr. M. Hansen, Christiania; K. Keilhack, Berlin; E. Zimmerman, Berlin; A. Jentsch, Königsberg; G. Berendt, Berlin; Dr. Greim, Darmstadt; Leo Wehrli, Zürich; Dr. Wahnschaffe, Berlin; A. W. Pavlow, Moscow; Willi Ule, Halle; Dr. Fritz Regel, Jena; A. P. Pavlow, Moscow; Aug. Aeppli, Zürich; F. Mülhberg, Aarau; E. Flournoy, Genève; J. Lorié, Utrecht; Immanuel Friedlaender, Berlin; A. Woeikof, St. Petersburg; Hav. Pfeiffer, Dugald Bell, Glasgow;

Adolf Forster, Wein; A. Schenck, Halle; Bernard Hobson, Manchester.

Dr. Geikie will give in the next number of the JOURNAL OF GEOLOGY a classification of European glacial deposits, in which he will propose a series of formational names analogous to those suggested by the present writer for the American formations in the sketch of these given in the last edition of *The Great Ice Age.*

T. C. C.

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AMERICAN geology has received a very gratifying testimonial of its appreciation abroad through the action of the Geological Society of London in conferring the Bigsby Medal upon Director Charles D. Walcott of the U. S. Geological Survey. It was the wish of Dr. Bigsby in providing for the medal that it should be awarded in "acknowledgment of eminent services in any department of geology, irrespective of the receiver's country," and that the recipient should not be older than forty-five years. This worthy recognition, designed to honor and encourage young and rising talent, coming so near the inauguration of his administrative service, will prove peculiarly auspicious and will strengthen the hands of the Director.

Congress has paid its compliments also to the new administration of the Survey in slightly increased appropriations. C.

PUBLICATIONS.

The Penokee Iron-Bearing Series of Michigan and Wisconsin. By R. D. IRVING and C. R. VAN HISE. Monograph U. S. Geological Survey No. XIX., 1892. Quarto, 534 pp.; with 37 plates representing microscopic sections of the rocks of the district, and geological sections and maps of the region.

The region discussed in this volume lies a few miles south of Lake Superior, partly in Michigan, partly in Wisconsin. It extends from Lake Gogebic in Michigan westward in a narrow strip from one to three miles wide, to Lake Numakagon in Wisconsin, a distance of about eighty miles. This area is covered by rocks of the Penokee series, which dip northward in a long and very regular monocline. The series is underlain by crystalline rocks designated the Southern Complex, though occasionally there intervenes between this and the Penokee series a formation designated the Cherty limestone. The Penokee series is overlain by the Keweenaw series, which in turn is overlain by the Eastern Sandstone.

The Southern Complex is considered to be of Archean age and is discussed more fully in another part of this review by Professor Iddings. It was much eroded and reduced almost to base level before the deposition of the overlying formations.

The cherty limestone is considered to belong to the Lower Huronian division of the Algonkian. It is composed of cherty, dolomitic limestone alternating with layers of chert, and averages about 300 feet in thickness. It is not continuous throughout the region, but is found intermittently between the Southern Complex and the Penokee series. A period of erosion of this formation occurred before the deposition of the overlying series, but it was of far less magnitude than the preceding period of erosion of the Southern Complex.

The Penokee series is considered to be the equivalent of the Animikie, and belongs to the Upper Huronian division of the Algon-

kian. It is composed of three members designated in an ascending order as the Quartz-Slate member, the Iron-bearing member, and the Upper-Slate member. All of these lie conformably with each other, but differ considerably in the character and the mode of deposition of their constituents. The Quartz-Slate and Upper-Slate members are of clastic origin, while the Iron-bearing member is largely composed of chemically deposited materials.

The Quartz-Slate member is about 500 feet thick, is composed of fragmental materials among which quartz predominates, and is capped by a layer of pure quartzite, which has played an important part in the formation of the iron ore bodies. The Iron-bearing member averages about 800 feet in thickness, and is composed of cherty iron carbonates, ferruginous slates and cherts, and actinolitic and magnetitic slates. The cherty iron carbonates are the original form from which the other rocks mentioned were derived. The iron ore deposits of the region were also formed from the same sources and in a manner to be discussed more fully below. The Upper-Slate member averages about 12,000 feet in thickness. It is of clastic origin, and composed mostly of graywackes or graywacke-slate, though sometimes altered to a crystalline schist.

Numerous bodies of diabase have been intruded into the Penokee series, both in the form of dikes and of interbedded sheets probably contemporaneous with the dikes, both being presumably of Keweenawan age. These diabase intrusions have had a most important effect on the formation of the iron ore deposits, as will be noticed later on.

The Penokee series was subjected to a period of considerable erosion before the depositions of the overlying Keweenaw series, and this in turn was again subjected to disturbance and erosion before the deposition of the overlying Eastern Sandstone. It will thus be seen that the Penokee series is separated by marked unconformities, both from the underlying Southern Complex on the south and the overlying Keweenaw series on the north; while it is terminated on the east by the Eastern Sandstone and is abruptly cut off on the west by erosion. It occupies, therefore, an isolated area, unique among rocks of this age for the clear definition of its members and the simplicity of its structure.

The iron deposits which have made the Penokee region (also known as Penokee-Gogebic region) celebrated as a mining district, occur in the lower horizon of the Iron-bearing member of the Penokee series, and generally immediately over the quartzite which forms the uppermost horizon of the Quartz-Slate member. The diabase dikes which

occur in the Penokee series came up partly, at least, before the enclosing rocks assumed their present position, and they have since been subjected to the same disturbance which developed the monoclinal structrue of the region. The result is that in places where the dikes intersected the quartzite of the Quartz-Slate series V-shaped troughs have been formed, opening upwards and bordered on one side by diabase and on the other by quartzite. In these troughs, of course, were originally included V-shaped masses of the cherty iron carbonates of the Iron-bearing member which immediately overlies the quartzite. This material contained too little iron to be of commercial value, but by a process of chemical concentration in the V-shaped troughs, rich bodies of pure hematite have been formed. It is shown that during the process of erosion and superficial oxidation one side of the V-shaped mass of cherty iron carbonates was oxidized more rapidly than the other, so that the iron in it was converted to sesquioxide, while the iron in the other side was still in the form of carbonate. Surface waters percolating through the oxidized part of the V-shaped mass, therefore, continued down without losing much of their oxygen, for the materials which they met in their course had already been oxidized. These waters in descending met one of the sides of the V-shaped trough and were deflected down to where the two sides met, with considerable oxygen still in solution. Surface waters, however, percolating through the less thoroughly oxidized part of the V-shaped mass lost their oxygen in oxidizing carbonate of iron in the unoxidized cherty iron carbonates, but in turn they received carbonic acid from the decomposed carbonate. This enabled them to dissolve some of the iron carbonate not yet decomposed; and thus ladened with iron in solution, they percolated down, and were deflected by the other side of the trough into its lower part. Here they met the waters containing oxygen which at once oxidized the iron held in solution and precipitated it in a sesquioxide condition. In this way the large bodies of iron ore were collected; and by the same waters that brought the iron into the trough the silica in the cherty material was removed, thus leaving a pure iron ore. It is evident that during the erosion of the cherty iron carbonates the iron from them would be gradually leached out and carried into the trough, instead of lost in surface waters.

The evidence that such a process has gone on is very strong and has been presented in a most admirable manner by Professor Van Hise, whose work shows very clearly the fallaciousness of the old idea that the

iron deposits were simply layers interbedded with the associated rocks. The same theory of the formation of iron deposits, changed a little to suit local details, might consistently be applied to many iron deposits in the eastern states and in the Rocky Mountains, though of course the trough in which concentration occurred need not necessarily have been formed by a dike and a quartzite, as in the Penokee region. The trough may be formed in a great number of ways, by disturbances and foldings in the rocks without any dikes, by the crumbling of local areas of rock, etc.

In addition to the purely geological part of the volume, a chapter on previous geological work in the district and a full summary of the literature is given. A most excellent feature of the volume is the system of clear, brief summaries at the end of each chapter and the general outline of the volume given in the beginning, both of which are of the greatest value in giving a correct understanding of the subject, as well as a convenient means of rapid reference.

R. A. F. PENROSE, JR.

The Petrology of the Penokee Iron-Bearing Series.

As an example of the value of petrographical study, both of the rocks of a metamorphosed series, *per se*, and of the production of a metalliferous deposit of great economic importance, the monograph by Irving and Van Hise stands preëminent. Not only has the investigation been thoroughly and skillfully made, but the data obtained have been presented in such a manner as to render them accessible to those who may wish to follow the investigation step by step, and be able to form, as it were, an independent opinion. At the same time the results are stated in a concise form with sufficient explanation for those who do not care to follow the study in detail. This has been accomplished by placing the results in the form of general statements, and by supplementing them with a tabulation of the observations. In the case of each formation studied the field occurrence and megascopical structure have been combined with the microscopical characteristics in shaping the history of the formation. And the probable origin of each has been reasonably demonstrated.

Owing to the fullness of the petrographical portions of the report, which, in fact, constitute the foundation of the work, it will not be possible to do justice to it in a brief review, in which only a few of the salient features can be pointed out. The most notable of these are in

connection with the terrane of crystalline schists underlying the Penokee series, and known as the Southern Complex. The first is the diverse petrographical character of these rocks and their probable igneous origin. The second is the author's use of the term granite. These will appear from the following digest:

The Southern Complex is considered to be Archean, and is designated on the map as granite, granitoid-gneiss, schist and fine-grained gneiss. In the text these rocks are said to be exceedingly complex both as to their lithological character and structural relations, comprising unmistakable eruptives, including diabases (considered post-Archean in age), syenites, gneissoid-granites, granites, and many different varieties of gneisses and schists. The areas of granite and schist alternate with one another, and are associated in such a manner as to indicate that the latter are metamorphosed forms of the granites. Instances of the alteration of feldspar to quartz and biotite are described, and the changing of a feldspar-rock into a mica-schist. The "Western granite" area consists of "granite and gneissoid granite," the latter varying in structure from almost granitic to "extremely contorted and quite finely foliated." The mineral composition is nearly constant throughout this area and is that of granite. The "Western green schists" are distinct from the rocks just noted. In different parts of the area they have very different characters. Most of them are finely schistose gneisses of various kinds, some appear to be highly altered basic eruptives. The "Central granite" has a large area and is both granitic and gneissoid. "The rocks here included vary greatly in their chemical composition, running from granites to gabbros. The three chief types of rocks are the granites, the syenites, and the gabbros." Concerning the "Eastern granite" the author says: "The phase here included run from typical syenites to typical quartzose granite."

The diabases occurring in the Southern Complex are considered to be contemporaneous and in some cases continuous with those forming dikes in the Penokee series.

The author states that "the kinds of rocks mentioned in the Southern Complex are not necessarily all which may there exist," since only a fraction of the exposures were visited. The most important fact developed by the study of this complex is the apparent gradual change between the massive rocks and the schistose ones, and the conclusion that the latter are metamorphosed eruptive rocks.

It is evident that in the region described the Archean formation consists of rocks of widely different composition, and that the variations are frequently repeated throughout the area.

The use of the term granite in a general sense for granular rocks, without regard to their composition, must naturally preclude its use in the narrower petrographical sense. The need of some widely applicable terms to designate groups of rocks resembling one another in outward, megascopical appearance is becoming more and more urgent as the refinements of advanced petrography tend to discriminate more closely upon a basis of characters not distinguishable in the outward appearance of rocks. The necessity of maintaining terms which may be applied to rocks by those not conversant with petrographical methods of investigation, or which may be used until the precise character of the rock has been discovered, must be evident to all geologists. The same term, however, should not be used in a general and in a restricted sense. As others have pointed out, *granite* may properly be employed as a general term for all phanerocrystalline, evenly granular rocks. A new term would be required for such rocks, when composed of quartz, alkali-feldspars with or without ferro-magnesian silicates.

The petrographical study of the members of the Penokee series has led to the conclusion that the chert and limestone of the cherty limestone member are water-deposited sediments, whose origin is not improbably organic, the silica having been rearranged and the limestone dolomitized. The study of the quartz-slate member shows its composition to be varied; that it is always fragmental, and that its induration is due to the secondary enlargement of quartz fragments, rarely of feldspar fragments. It is also due to the alteration of the feldspar to biotite, chlorite and quartz by the accession of material from neighboring sources. The source of the original fragments composing this formation was chiefly the Southern Complex.

The petrographical study of the Iron-bearing member has demonstrated satisfactorily the origin and mode of formation of the ore-bodies, the substance of which is reviewed more particularly by Professor Penrose.

The upper slate member was found to be of fragmental origin, and was derived from the Southern Complex. Metasomatic changes have altered the original deposits to a greater or less extent; the extreme metamorphism resulting in rocks in no way distinguishable from crystalline schists. This change has been most complete in nearly pure

arkoses which have been converted into mica-schists. The change of feldspars into biotite and quartz is notable.

The eruptive rocks cutting the Penokee series in the form of dikes and sheets are normal diabases, occasionally grading into gabbro. The chief feature of interest developed in their study is the fact that their freshness and alteration is closely dependent on the permeability of the adjacent rocks to percolating waters, showing that environment may be a more important element than age in the preservation of a rock.

The formations composing the Eastern area of the Penokee series have been modified by contemporaneous volcanic action, and the accumulation of surficial lavas, both massive and fragmental. These were of a basic character, some being porphyrites, others diabases, grading into gabbros that are considered to be deep-seated parts of the lavas. These rocks have been altered into greenstones. The other rocks of the Eastern area resemble those of the Western area in petrographical characters.

In the closing chapter of the monograph the flexures and faults are discussed, and the structure of the region is described. The Penokee series is correlated with the Animikie series, and also with the Marquette. Other correlations are suggested.

JOSEPH P. IDDINGS.

Summary of Current pre-Cambrian North American Literature.[1]

Cross[2] describes intrusive sandstone dikes in the Pike's Peak granite. The material has all the characteristics of dikes. The larger number are a few inches or a few feet thick, but they vary from a film to those three hundred yards wide. Some of the larger have been followed for nearly a mile. The dykes have a general trend parallel to the belt in which they occur, and they are connected in an intricate way by diagonal fissures, and all are regarded as belonging to a single fissure system. The material of the dikes is fine and even-grained sand grains, either in the form of sandstone or more commonly indurated to a dense hard quartzite. The induration is mainly due to limonite, but in some degree is due to muscovite, and to secondary silica. The

[1] Continued from p. 454, Vol. II. JOURNAL GEOLOGY.

[2] Intrusive Sandstone Dikes in Granite, by WHITMAN CROSS. Bull. Geol. Soc. Am., Vol. 5, pp. 225–230, pl. 8, 1894.

physical and mechanical facts seem to show that the fissures of this complex were filled by fine quicksand, injected from an unknown source, containing a large amount of homogeneous material.

Peale[1] places the Belt formation of the Three Forks sheet in the Algonkian. This formation at the East Gallitan River is 2300 feet thick and consists of an alternation of coarse, micaceous sandstones and conglomerates, with beds of hard argillaceous slates, and bands of thin-bedded, dark blue, siliceous limestones. The latter are very hard and some are slightly magnesian. The limestones occur mainly towards the base of the section, in bands ordinarily from five to twenty feet in thickness, but sometimes reaching nearly fifty feet. On the Bridger range the formation has a thickness of at least 6000 feet. It is also characteristically exposed in the Cañon of Jefferson River fourteen or fifteen miles above its mouth.

Nowhere in the Gallitan valley is the belt formation found in immediate superposition upon the Archean, but that it is post-Archean is shown by its being made up largely of Archean débris. Between the Belt formation and the overlying Flat Head Cambrian quartzite there is no well defined unconformity, although there was an important orographic movement between the two, the entire area of the Three Forks sheet being submerged at this time. Little, if any, induration is seen in the Flathead formation, while the Belt beds are so altered in most cases as to resemble closely the metamorphic crystalline rocks which underlie them, and from which they were derived by their breaking down. Notwithstanding the metamorphism there is no mistaking the sedimentary character of the Belt formation.

We have, therefore, a non-fossiliferous formation of clastic beds, in some places highly metamorphosed, which lies between the Archean gneisses and a belt of quartzite, above which are beds with Middle Cambrian fossils. From its stratigraphical position this formation can be only of Lower Cambrian or of Algonkian age.

The possibility that Lower Cambrian fossils may yet be found in the quartzite at the base of the Flathead formation; the absence of organic remains in the Belt formation; the metamorphosed condition of the latter, and the existence of an orographic movement between the quartzite and the beds below lead us to refer the latter, for the present at least, to the Algonkian.

[1] The Palæozoic Section in the Vicinity of Three Forks, Montana, by A. C. Peale. Bull. 110, U. S. G. S., 1893, pp. 56.

McConnel[1] reports a small area of Archean gneisses on the northern shore and neighboring islands of Lake Athabasca, on the islands of Lake Mammawi, and in the tilted deposits bordering Quatre Fourchés River. The gneisses include hornblendic, micaceous, chloritic and epidotic varieties. In places they pass into a mica-schist or chlorite-schist. The gneisses strike from 10° to 20° west of north.

Bell[2] describes the pre-Palæozoic rocks of the north of Lake Huron as having been subjected in certain areas to vast denudation and decay before Palæozoic time. The evidence of this decay, most frequently found in granite, consists in hollows, pits, irregular ridges, and even small caverns, which are filled with Palæozoic limestone. These irregularities are regarded as having been formed at the bottom of the deep sea by solution. Had the erosion taken place on land there would be evidence of this in deeper decay in the substances of the rock and in the deposition of detrital deposits below the pure limestone, which in many cases rests directly upon the pre-Palæozoic rocks.

In the area between the foot of Lake Ontario and the head of Georgian Bay the contact of the Potsdam sandstone and Black River limestones with the underlying gneiss and quartzite is seen at many localities. These rocks are generally hard and fresh. The surface is irregular, and the whole has been buried beneath the horizontal Palæozoic rocks.

Many of the long narrow valleys of the Archean region are due to the decay and removal of wide greenstone dikes or parallel dikes, with the belts of rock between them. The greenstone dikes are never found to traverse the overlying Silurian, and it is supposed that these valleys were mostly formed before the deposition of the Palæozoic strata. It is thought that the larger part of this Archean area never received any of the Palæozoic rocks upon it, and that the surface of the Archean had been reduced to something like its present level and aspect before the Palæozoic deposits were deposited. As evidence of this are outliers of the Potsdam sandstone and Black river limestone filling similar narrow valleys.

Comments. It may be suggested that the evidence given that the

[1] Report on a Portion of the District of Athabasca, comprising the Country between Peace River and Athabasca River, North of Lesser Slave Lake, by R. G. McConnell. Ann. Rep. Geol. Sur. of Canada for 1890–1, Vol. V, Part 1, D, pp. 5–62, 1893.

[2] Pre-Palæozoic Decay of Crystalline Rocks North of Lake Huron. Bull. Geol. Soc. Am., Vol. 5, pp. 357–366, pls. 15, 16, 1864.

greater part of the Archean area was never covered by Palæozoic rocks is inconclusive, since it is stated that the pre-Palæozoic topography of the area covered by Palæozoic rocks is the same as that not so covered.

Adams[1] gives a preliminary description of Sheet 118 of the Canadian Survey, an area of about 3500 square miles, situated north of Lake Ontario, in the counties of Victoria, Peterborough and Hastings. The whole area is occupied by the rocks of the Laurentian system, with the exception of the southeast corner, which is underlain in part by the Hastings series. In the surrounding eastern portions there is an abundance of crystalline limestone, and the rocks have all the characteristics of the Grenville series of Sir William Logan. In the northwestern part of the area the country is apparently occupied by gneiss alone. The relations of the Grenville series to the gneiss free from limestone has not yet been definitely determined, although the limestone and the associated gneiss seem in certain cases to partially enclose areas which contain no limestone. Throughout the area occupied by the Laurentian rocks, the dip, are uniformly at an easterly direction, usually at moderate angles. Only at one or two points have westerly dips been observed, and these are quite local. The relations of the Hastings series to the Laurentian is also as yet uncertain. One of the most marked characteristics of this district is the great development of pyroxenic and hornblendic rocks, among which many are, without doubt, of eruptive origin. Also there are several large intrusive masses of granite, and a very extensive mass of nepheline syenite. Otherwise the Hastings and Grenville series are not very unlike petrographically.

In the area south of Sheet 118, in Dalton and the western part of Digby townships, is found reddish orthoclase gneiss, with dark, micaceous and hornblendic bands, which is cut in a complicated way by coarse-grained granite. In the eastern part of Digby township and in Lutterworth and Galway townships are found crystalline limestones, and the peculiar rusty weathering gneisses always associated with them. In the limestone districts various metalliferous ores are found.

[1] Preliminary Report on the Geology of a Portion of Central Ontario situated in the Counties of Victoria, Peterborough and Hastings, together with the results of an Examination of Certain Ore Deposits Occurring in that Region, by F. D. ADAMS. Geol. Sur. of Can., Ann. Rep., Part I., Vol. VI., pp. 15, 1894.

Low[1] describes the Archean of Portneuf, Quebec and Montmorency counties in Quebec. These rocks cover about 980 square miles, and are covered on the south by Cambro-Silurian limestones and shales. A rough section from west to east across the northern portion at right angles to the strike through lake Simon is as follows:

(1) Dark schistose mica-gneiss, interbanded with coarser red and gray mica-gneisses. 10 miles.

(2) Fine-banded gray, pink and red mica-gneisses, and mica-hornblende-gneisses. 10 miles.

(3) Dark gray garnetiferous hornblende-gneiss. 2 miles.

(4) Fine-banded gray, pink and red mica-gneisses and mica-hornblende-gneisses. 7½ miles.

(5) Dark green basic, crushed granitic gneiss. 1½ miles.

(6) Coarse red and gray augen-gneiss. 2½ miles.

(7) Fine-banded gneiss (2) and (4). 6 miles.

(8) Coarse red and gray augen-gneiss. 6 miles.

(9) Fine-banded gray and pink mica-gneiss. 14 miles.

(10) Anorthosite. 2 miles.

(11) Fine-banded, gray and pink gneisses. 12 miles.

In this section the rocks are grouped in accordance with the predominating kind, although bands of other varieties are included in all of the rough divisions. Divisions 1, 2, 3, 4, 9 and 11 appear to have been originally clastic rocks, subsequently completely metamorphosed into schists and gneisses, and subjected to great pressures, which have folded and twisted them so that their original horizontal succession is greatly obscured. The different bands are conformable and appear to grade into one another. The 5th division embraces rocks probably of igneous origin, which have been injected along a line of weakness between the banded gneisses and the coarser-grained rocks of the 6th division. The 6th and 8th divisions are usually gneissic, but often are granitic. They appear to underlie the banded gneisses, and are either the remains of older beds that have been re-fused or are original molten matter which has dissolved and floated portions of the banded beds, since fragments of them are enclosed in the coarser gneisses. The anorthosite is also igneous, having apparently been intruded in its present position after the formation of the banded gneiss with which

[1] Report on the Geology and Economic Minerals of the Southern Portion of Portneuf, Quebec and Montmorency Counties, Province of Quebec, by A. B. Low. Ann. Rep. Geol. Sur. of Canada for 1890–91, Vol. V., Part 1, L, pp. 5–82, 1892.

it is in contact. This contact is not sharp in places, as the gneisses usually seem to have been infiltrated by basic feldspar material from the anorthosite, causing a gradual passage from one to the other. At one place in division 11 appears a band of highly crystalline limestone.

At many places the Trenton limestone is found directly in contact with the Archean rocks. The surface of the Archean rocks on which these newer beds were laid down had a rounded undulatory form, closely resembling the present exposed surface. The gneisses and the limestone present fresh, undecomposed surfaces. At various places between the Trenton limestone and the Archean is a thin layer of calcareous sandrock, resting in the hollows of the Archean surface, which holds Trenton fossils. In one place in the limestone is found a bowlder of gneiss six feet long, four feet wide and four feet thick, which is supposed to have been dropped by floating ice.

Mathew, W. D.[1] describes the pre-Cambrian area near St. John, New Brunswick. The earliest series, or Laurentian, consists chiefly of granitic and gneissoid rocks, limestones and quartzite, the two latter being confined to the upper beds. The strata lie steeply inclined in a succession of ridges and folds striking in a general northeast and southwest direction. Overlying this more crystalline series, generally at a lower dip, are fine-grained flinty rocks, interbedded with various schists, porphyries, ash-rocks and sandstones, and with great masses and dikes of trap. These have been called Huronian.

The old part of the Laurentian consists of gneisses proper, accompanied by hornblende-schists and mica-schists, which in thin section show no trace of igneous origin, and of limestone and quartzite. Associated with the less crystalline limestones are beds of fine-grained black rock, which has generally been called argillite. Much of the Lower Laurentian series consists of granite, diorite and gabbro, which are igneous rocks. The granite intrudes both the gabbro and the sedimentary series as is shown by contact effects and by veins and pegmatite masses adjacent to the granite in the sedimentary series. As to the age of this intrusion, it may be as late as Devonian, but as the granite is cut by innumerable dikes which also cut the Huronian and the Palæozoic, it is very likely that the intrusion is pre-Huronian. The great unconformity in the district is between the Laurentian and Huronian, not between the Huronian and Cambrian.

[1] The Intrusive Rocks near St. John, New Brunswick, by W. D. MATHEW. Trans. N. Y. Acad. Sci., Vol. XIII., pp. 185–203, 1894.

Ells[1] states that the mica and biotite of the Laurentian of Canada is confined to a horizon composed of a series of gneisses of the upper portion of the Laurentian, siliceous rocks which underlie the limestone proper. This horizon graduates upward by regular passage through the interstratification of calcareous layers into the massive crystalline limestone formation.

Whittle[2] describes the main axis of the Green Mountains as a series of sharp, compressed folds striking approximately north and south and overturned to the west in most localities so that induced schistosity and stratification dip eastward. Localities on the western border have a steep westerly dip in many instances; in others the border series as a whole is nearly in a vertical position. Many areas occur along this belt where the series is overturned to the west, but the exact angle at which the strata lie is difficult of determination. The orographic thrust producing the folding was directed nearly east and west. Normal faults and overthrusts are indicated, but data for their detection are not now at hand except in one instance.

Whittle[3] describes the pre-Cambrian rocks of Vermont as consisting of two series of Algonkian rocks. The Lower Cambrian quartzite is apparently underlain conformably by the upper of the two, or the Mendon series. That the two are, however, really unconformable is supported, among others, by the following reasons: The extreme lithological diversity of the metamorphic series as compared with the quartzite; a close folding in the Mendon series not observed in the quartzite, and by the fact that the quartzite reposes discordantly upon granitoid gneiss to the southward.

The Mendon series consists in descending order of the following members: mica-schist, with a maximum thickness of 1000 feet; micaceous quartzite, having a maximum thickness of 500 feet and carrying several thin beds of crystalline limestone; crystalline limestone, with a maximum thickness of 400 feet; conglomerate schists and quartzite with a maximum thickness of 700 feet. At Mendon the section has

[1] Mica Deposits in the Laurentian of the Ottawa District, by R. W. Ells. Bull. Geol. Soc. Am., Vol. 5, pp. 481–488, 1894.

[2] General Structure of the Main Axis of the Green Mountains, by C. L Whittle. Am. Jour. Sci., Vol. XLVII., No. 281, pp. 347–354, May, 1894.

[3] The Occurrence of Algonkian Rocks in Vermont and the Evidence for their Subdivision, by C. L. Whittle. Jour. Geol., Vol. II., No. 4, pp. 396–429, May–June, 1894.

an approximate thickness of 1300 feet, and in some localities there may be 2000 feet of strata in the series.

The lower series of Algonkian, called the Mount Holly series, is contrasted with the Mendon series in nearly every way. The structure of the series is so complicated, the different rock types vary so greatly and the series has been subjected to such a multiplicity of dynamic movements, that no definite stratigraphy has been made out. Some of the prominent rocks of the series are biotite-schist, muscovite-schist, garnetiferous schist, vitreous quartzite, augen-gneiss and various kinds of limestone. The limestones are in irregular lenses, and are extremely local. There may be two horizons of limestone or a dozen. The series, because of the undoubted areas of sedimentary rocks which have escaped destruction, are regarded as clastic. Associated with the above rocks are very abundant schistose, igneous rocks, comprising both dikes and sheets.

The two series of Algonkian rocks are regarded as unconformable for the following reasons: Between the two there is a great lithological difference; the Mount Holly series has been cut through by eruptive rocks in a complicated fashion, and these do not occur in the Mendon series; the Mount Holly series is folded in a much more intricate manner than the Mendon series, and secondary structures have developed to a far greater degree; at the bottom of the Mount Holly series is a widespread formation of conglomerates and gneiss. The schistosity of the two series is parallel, but this is regarded as due to disintegration before the Mendon series was deposited, and to post-Mendon folding.

Smyth, C. H.,[1] gives a petrographical description of the gabbros of the southwestern Adirondack region, and of black hornblende-gneiss which occurs in the same area. The most altered form of the gabbro is very similar to the hornblende-gneiss, and it is suggested that the latter is but an extremely metamorphosed phase of the former.

Smyth, C. H.,[2] describes a group of diabase dikes as breaking through the granite, gneiss and quartzite in the vicinity of the village of Gannanoque, Ontario, the whole being overlain by Potsdam sandstone.

[1] Gabbros in the Southwestern Adirondack Region, by C. H. SMYTH, JR., Am. Jour. Sci., Vol. XLVIII., No. 283, pp. 54–80, July, 1894.

[2] A Group of Diabase Dikes among the Thousand Islands, St. Lawrence River, by C. H. SMYTH, JR. Trans. N. Y. Acad. Sci., Vol. XIII., Sig. 14, pp. 209–214, August, 1884.

Kemp[1] describes the gabbros of the western shore of Lake Champlain. The rocks occurring in this area comprise: (1) gneisses, (2) crystalline limestones, including black hornblendic and pyroxenic schists and gneisses, and (3) anorthosites, including gabbro proper, olivine-gabbros and uorites. The anorthosites over large areas have been profoundly affected by dynamic action, and in many places now have a gneissic structure. In the anorthosites at various places and particularly at Split Rock Mountains, forming the more basic crystallization from the original magma, are lean, titaniferous magnetites which have been mined as iron ores. At the contacts of the gabbro and limestone the latter rock has been bent by dynamic movements; various silicates have developed within it, among which are scapolite, hornblende, pyroxene and titanite. The limestone is also coarsely crystalline. Since the intrusion of the gabbro the limestone has been subjected to dynamic movements, and exhibits strongly the characteristic plasticity of this rock under stress.

Kemp and Hollick[2] find the granite at Mounts Adam and Eve, N. Y., to be intrusive within the limestone. Adjacent to the granites the limestone is white and crystalline and is charged with peculiar contact minerals. This white limestone graduates into blue limestone with transitional graphitic forms. The continuation of this limestone in New Jersey contains Cambrian fossils.

Nason[3] finds as a result of analyses that the white and blue limestone of Sussex county, N. J., are essentially the same in composition, both being magnesian limestones or true dolomites. The coarsely crystalline white limestone near its contact with granite is generally non-magnesian.

Nason[4] gives a summary of facts showing that the white limestone of Sussex county is of Cambrian age, as follows;

[1] Gabbros on the Western Shore of Lake Champlain, by J. F. KEMP, Bull. Geol. Soc. of Am., Vol. V., pp. 213–224.

[2] Granite at Mounts Adam and Eve, Warwick, Orange County, N. Y., and its Contact Phenomena, by J. F. KEMP and ARTHUR HOLLICK, Annals of the New York Acad. Sci., Vol. VII., pp. 638–654.

[3] The Chemical Composition of some of the White Limestones of Sussex County, N. J., by FRANK L. NASON, Am. Geol., Vol. XIII., No. 3, pp. 154–164, March, 1894.

[4] Summary of Facts Proving the Cambrian Age of the White Limestones of Sussex County, New Jersey, by F. L. NASON. Am. Geol., Vol., XIV, No. 3, pp. 161–168, September, 1894.

1. The white limestones are continuous with the blue limestones (now accepted as of Cambrian age) and every degree of transition may be found between them.

2. Both have the same strike and dip.

3. Both are conformable with a quartzite also containing Cambrian fossils.

4. Both are unconformable with the gneiss upon which they rest.

5. Both have in sum total the same chemical composition and are magnesian.

6. The altered crystalline condition of the white limestone is due to the intrusion of igneous masses and to regional metamorphism, while the blue limestone never contains such igneous injections.

7. The presence of certain minerals, especially chondrodite, is not indicative of geological age, as this mineral is known to occur in modern volcanic rocks.

Westgate[1] holds that the crystalline limestones of Warren county, New Jersey, are distinct from and older than the blue Magnesian limestone, and of pre-Cambrian age, for the following reasons: They have a well developed crystalline character, and hold large quantities of accessory metamorphic minerals; they show no intimate association with the blue Cambrian limestones; they show no tendency to grade into them; they have been subjected to general metamorphic forces, of which the neighboring blue limestone shows no trace; they occur in intimate association with the granitoid gneisses, and in some cases appear to be interbedded with them.

Grimsley[2] describes and maps the rocks of a part of Cecil county in northwestern Maryland. The rocks are granite, diorite, and staurolitic mica-schist. The staurolitic mica-schist is regarded as a sedimentary rock. In this the granite-gneiss is intrusive, as shown by the fact that branching dikes and apophyses penetrate the adjoining schists and slates, producing pronounced contact effects upon them. The diorite occurs in dikes in the granite.

C. R. VAN HISE.

[1] The Age of the Crystalline Limestones of Warren County, New Jersey, by L. G. WESTGATE, Am. Geol., Vol. XIV., No. 6, pp. 369–379, December, 1894.

[2] The Granite of Cecil County in Northwestern Maryland, by G. P. GRIMSLEY, Journ. of Cincinnati Soc. Nat. Hist., pp. 50, April and July, 1894.

Pithecanthropus erectus eine menschenähnliche Übergangsform aus Java von Eug. Dubois, Militärarzt der niederländisch-indischen Armee mit zwei Tafeln und drei in den Text gedruckten Figuren. Batavia Landesdruckerei, 1894, 39 p. 4to.

Between 1889 and 1893, by the order of the Governor-General of Dutch India, palæontological researches were made by Dr. Eugen Dubois, in Sumatra and Java. The result was a good collection of Pleiocene and Pleistocene vertebrates. The most important find consisted of portions of an anthropoid form, which is considered the missing link between the Simiidæ and Hominidæ. The remains consisted of the upper portion of a skull (similar in preservation to the well-known Neanderthal skull) a third upper molar, and the left femur, which were found near Trient, on the Isle of Java. The history of the find is this: In the left bank of the river Bengawan, about 1 m. below the watermark of the dry season, 12–15 m. below the eroded level, the molar was found in September, 1891. One month afterwards, in the same level, at a distance of 1 m., the cranium was found, and in August, 1892, 15 m. further up the river, and again, in the same horizon, the femur was brought to light. Dr. Dubois considers these remains as the parts of one individual.

The name *Pithecanthropus erectus* is given to the fossil. This name had already been used by Professor Haeckel in 1868 in his "Natürliche Schöpfungsgeschichte" for a hypothetical anthropoid, who walked upright, was mentally more developed than the anthropoid apes, but without language.

Pithecanthropus is placed by Dubois in a special family, *Pithecanthropidæ*, between the Simiidæ and Hominidæ with the following character:

"Brain cavity, absolutely and relatively, much larger than in the Simiidæ, but smaller than in the Hominidæ. Capacity of cranium about two-thirds of the average capacity of man. Inclination of cervical portion of occipital bone much stronger than in the Simiidæ; dentition in reduction, but of the pattern of the Simiidæ. Femur similar to that of man in its dimensions, and constructed for erect walking."

Dr. Dubois gives a table of the different values of the cranial capacity in the Simiidæ and man, and reaches the conclusion that the capacity of *Pithecanthropus* is over 1000 cubic centimeters, or over two-thirds of a human cranium of more than average size.

The femur is 455 mm. long, and in nearly every respect like that of man; slight differences are only seen in the absence of an Angulus medialis, in the slight development of the Planum popliteum and the Linea obliqua, and in the concave form of the Crista intertrochanterica. The corresponding size of man, with a femur of 455 mm. is given as 170 cm.

The important question, of course, is asked: Is the material at the disposition of Dr. Dubois sufficient to sustain the conclusions so confidently expressed. We know that the capacity of the normal human cranium varies from 1000–1800 cubic centimeters; *Pithecanthropus*, with a capacity of over 1000, is not necessarily excluded from this series. In regard to the femur it is questionable whether the distinctive characters given by Dr. Dubois hold good, if a great number of human femora is examined; besides, the femur shows an extensive exostosis in the upper half. The evidence brought forward by Dr. Dubois certainly does not seem sufficient for the establishment of a new genus and family, forming the missing link between the Simiidæ and Hominidæ. The publication of the fauna contemporary with *Pithecanthropus* is looked for with much interest.

G. Baur.

The Fins of Ichthyosaurus.

As far back as 1838 Owen[1] had noticed the fact that nearly all the specimens of Ichthyosaurus from the English Lias showed a dislocation in the tail-vertebræ. This dislocation or bend was found at the posterior one-third of the tail, generally about the thirtieth caudal vertebra in the *Ichthyosaurus communis;* the terminal portion continued, after the bend, almost as straight as the portion of the tail preceding it. From this Owen reached the conclusion that Ichthyosaurus possessed a terminal tegumentary and ligamentous vertical caudal fin. By the weight of this fin, or by the force of the waves beating upon its extended surface, the break of the tail was produced. In the restaurations of Ichthyosaurus the tail was figured unbroken, with a caudal fin extending symmetrically above and below in a vertical plane, and ending in a point at the end of the vertebral column.

[1] Owen, R.: Note on the dislocation of the tail at a certain point observable in the skeleton of many Ichthyosauri. Trans. Geol. Soc., 2d Ser., Vol. V., pp. 511–514, pl. 42.

In 1892 Dr. E. Fraas[1] described a specimen of Ichthyosaurus from Holzmaden, Würtemberg (Museum, Stuttgart), in which the whole skin of the animal was preserved. The fin proved to be quite large, symmetrical, and of the same shape as that of the sharks, but the vertebræ did not extend to the dorsal but to the ventral lobe of the fin, thus demonstrating that the dislocation in the tail was the natural condition.

The same specimen showed that there existed a very large dorsal median fin, placed a little in front of the pelvic fins. The pectoral and pelvic fins were also beautifully preserved, and showed, what had been known already before, that the fleshy part of the paddles extended very much further backwards than the bony skeleton.[2]

Nearly at the same time a splendid specimen of a tail fin of Ichthyosaurus of very large size was found in the lithographic limestone of Solenhofen, and is now preserved in the Munich Museum; another tail fin from Holzmaden has gone to the Berlin Museum; and a very complete specimen, showing the whole skin, has lately been secured from Mr. W. Hauff, Holzmaden, by the Museum of Freiburg (Switzerland), for the sum of $750. In many specimens, which are now in the different museums, the skin could probably have been preserved, if anyone had thought of the existence of it. In the future it will be possible, by very great care.

It is of very great interest that we know now the real structure of the fins of the Ichthyosauria. It is well known that the Ichthyosauria originated from land-living reptiles closely related to the Rhynchocephalia and Proganosauria;[3] that the fins have been gradually developed through the adaptation to marine life is clear; it would be very interesting to find out whether the Triassic Ichthyosauria, in which the limbs are less specialized, show already the same structure in the tail as the forms from the Jurassic.

We see that a very similar fin structure is developed in two groups of animals belonging to two entirely different classes. In the Sel-

[1] Fraas E.: Über einen neuen Fund von Ichthyosaurus in Würtemberg. Neues Jahrb. f. Min. 1892, pp. 87–90.

[2] A very good photographic reproduction of the specimen is given by Fraas in Jahreshefte des Vereins f. vaterl. Naturkunde in Würtemberg, 1894. Taf. V.

[3] G. Baur on the Morphology and Origin of the Ichthyopterygia. Am. Naturalist, 1887, p. 837.

Über den Ursprung der Extremitäten der Ichthyopterygia. Vers. Oberrhein. Geol. Verein., 1887, Stuttgart, 4 p., 4 fig.

achians the vertebral column ends in the upper, in Ichthyosaurus in the lower lobe of the caudal fin. An explanation of this fact has lately been given by Professor Franz Eilhard Schulze[1] of Berlin.

By the lateral motion of a caudal fin like that of the Selachians in form, the animal can not only be propelled forwards, but also upwards or downwards. The motion will be forwards and upwards if, as in the sharks, the upper edge of the caudal fin is the stronger one; it will be forwards and downwards if, as in the Ichthyosauria, the lower edge of the fin is the stronger, supported by the caudal vertebræ. The sharks, as it is well known, are heavier than the water; the motion upwards, therefore, produced by the motion of the lower portion of the tail, is of the highest value for the sharks. The Ichthyosaurs on the other hand were as reptiles with lungs, and with the extensive layer of fat, lighter than water. For these the motion of the upper portion of its caudal fin, producing a downward motion, is of the greatest value.

G. BAUR.

[1] SCHULZE, FRANZ EILHARD: Über die Abwärtsbiegung des Schwanztheils der Wirbelsäule bei Ichthyosauren (Sitzungsber. Berliner Akad. 1894, p. 1133).

THE

JOURNAL OF GEOLOGY

APRIL-MAY, 1895.

THE CLASSIFICATION OF EUROPEAN GLACIAL DEPOSITS.

When the "Superficial Formations" of Europe began to attract attention, geologists soon discovered that these could be naturally classed under two heads. The lower and therefore the older deposits were characterized especially by their confused and tumultuous appearance, while the overlying younger formations showed a more or less orderly arrangement in layers or beds. The confused accumulations of the lower group were generally believed to be the products of some kind of cataclysmic action—perhaps, as some thought, the Noachian Deluge, or, according to others, mysterious debâcles and waves of translation, caused, it was imagined, by titanic disturbances of the earth's crust. By common consent the tumultuous deposits came to be known as *Diluvium*, while the overlying bedded accumulations were termed *Alluvium*, and were attributed to the action of water under those normal conditions of the surface that now obtain. It is unnecessary to ask why the diluvial explanation of the drift-phenomena ever commended itself to competent observers. Perhaps geologists had not yet quite freed themselves from the influence of their predecessors, whose heroic attempts to cut Gordian knots figure so prominently in the early literature of the science. One thing is certain that the principal advocates of the diluvial doctrine were ignorant of modern glacial action, and, with a few notable exceptions, had only the

most cursory acquaintance with the phenomena which they sought to explain. That their diluvial notions should have appeared reasonable to themselves and satisfactory to their disciples, who knew less, need not surprise us. Even in our own day we may see how the same doctrines can appeal to one who has merely a superficial literary acquaintance with the subject. The copious outpourings of Sir H. H. Howorth, if they have neither aided nor retarded the advance of glacial geology, have at least shown what a large field of profitless labor the pseudo-scientific wise men of Gotham have hitherto neglected to cultivate.

Long after the various diluvial hypotheses had been abandoned, and the glacial origin of the so-called *Diluvium* had been recognized, the deposits included under that term continued to be lumped together. Certain accumulations in mountainous countries, it is true, were believed to be moraines of local glaciers, but the "great northern drift" of the European low-grounds was looked upon as iceberg-droppings, and the whole diluvial formation was considered one and indivisible. Even after the dressed rock-surfaces and bowlder-clays of lowland regions had been assigned to the action of glaciers and ice-sheets, geologists continued in the belief that the Diluvium was the product of one protracted period of cold conditions. For a long time the only classification attempted was the subdivision of the drift series into morainic and marine accumulations. No one had as yet suspected the existence of what are now known as interglacial beds. Some of these, it is true, had been examined and described, but their true relation to the glacial deposits had not been recognized. Thus, up to a recent date, geologists—whatever their views might be as to the subglacial or submarine origin of the "drift" as a whole—did not doubt the unity of the Glacial Period. It was in Switzerland that the true meaning of interglacial deposits was first ascertained. Morlot, Heer, and others have put on record the observations which led them to conclude that the Alpine Lands have been subjected to two successive glaciations—the one separated from

the other by a prolonged epoch of erosion and accumulation, under climatic conditions somewhat similar to those now existing. Meanwhile, geologists in Britain had discovered that the drift deposits formed a triple series—namely, (*a*) lower bowlder-clay, (*b*) middle sand and gravel, and (*c*) upper bowlder-clay. And some were inclined to consider this grouping as roughly corresponding to the threefold arrangement of the Swiss deposits, and to infer that in the British area there had been two glacial epochs separated by an interval of submergence, when somewhat milder climatic conditions prevailed. In Germany, likewise, an "upper" and a "lower" Diluvium had been recognized long before the true significance of these groups dawned upon geologists. As observations increased it was found that here and there, in Scotland and elsewhere, beds of peat and fossiliferous fresh-water deposits appeared intercalated in bowlder-clay, or separating a lower from an upper bowlder-clay. By those who were of opinion that bowlder-clay is a ground moraine these intercalated beds were looked upon as evidence of glacial oscillations, of no great magnitude. It was supposed that the former glaciers and ice-sheets were subject, like their modern representatives, to temporary movements of advance and retreat. During a time of retreat vegetation spread over the ground vacated by the ice, and when the next forward movement took place the glaciers reoccupied the area invaded by plants, and buried the old soils under fresh accumulations of glacial débris. The upholders of the iceberg origin of the drifts did not attempt to account for the appearance of such intercalated fresh-water beds. It was easier to belittle their importance or to ignore them altogether. The deposits in question have now been encountered, however, in so many formerly glaciated areas that it is no longer possible to pass them by as accidental occurrences that may in time be somehow or other explained away. Their true significance is now the only question in dispute. Do they indicate mere local and temporary movements of glacial retreat and advance, or are they relics of long-continued milder conditions occurring between separate and distinct glacial epochs?

At first sight the former view appears the more reasonable, and to those who have never studied the phenomena accompanying interglacial deposits, it naturally has a special attraction. It is so simple, and so much in accordance with what is actually known of modern glacial action, that those who hold it may be excused for wondering why it is not generally accepted. We are referred to the glaciers of New Zealand which descend into the region of tree-ferns, and to certain glaciers of the Himalaya and Alaska with their tree-covered moraines, and are asked to consider how readily in those regions vegetable débris may become entombed in glacial accumulations. But there is no need to go so far abroad for similar phenomena. Even in the Alps in our day glaciers have advanced and buried trees and vegetable soil under their moraines. Unfortunately, however, none of these cases helps us to account for the interglacial beds of temperate Europe. If the latter never yielded other than Arctic-alpine plants something might be said for the explanation in question. During the climax of the glacial period, when the Scandinavian "inland-ice" invaded the low grounds of middle Europe, those low grounds supported an Arctic-alpine flora. It is obvious, therefore, that when temporary retreats and advances of the ice-front took place, the only relics of plant-life that were likely to be preserved in glacial deposits would be Arctic forms. But although such are not wanting at certain horizons in the glacial series, yet the most conspicuous interglacial beds are charged with the relics of a flora and fauna which could not possibly have flourished in the immediate vicinity of a great ice-sheet. Indeed, the interglacial beds, traced at intervals from Holstein through the heart of Germany to central Russia, contain a flora indicative of more genial conditions than are now met with in the same regions. One may feel quite sure that when the low grounds of middle Europe were clothed with such a flora, and tenanted by elephants and other large herbivora, no great Scandinavian ice-sheet could have existed. There is no reason to doubt, in short, that the snow-fields and glaciers of interglacial Europe were not more prominent than those of the Europe of today. And yet the

interglacial deposits referred to rest upon and are covered by glacial and fluvio-glacial accumulations. Here, then, we have to do not with mere local oscillations of an ice-front, but with great climatic changes extending over protracted periods of time.

But this is not all,—the long persistence of interglacial conditions is further shown by the amount of denudation and valley-erosion accomplished during interglacial epochs. The best examples I can cite are those described by Professor Penck and others as characteristic of the Alpine Lands. In the valleys descending to the north three conspicuous gravel-terraces may be noted, rising one above the other. The highest displays an average thickness of about 100 feet—its upper surface being some 250 feet above the level of the present rivers. The second terrace (eighty feet or so in thickness) rests like the former upon solid rock, and its upper surface is 130 feet or thereabout below that of the older terrace. The third and lowest terrace, occurring inside the preceding, rests also upon solid rock, and its upper surface is some 125 feet below that of the second terrace. Each of these terraces is of fluvio-glacial origin, and directly connected with a separate series of glacial moraines. Obviously the tale they tell is one of glacial accumulation and interglacial erosion. After the formation of the highest terrace the glaciers retreated, and fluvio-glacial accumulation ceased. The rivers then slowly dug their way down through the fluvio-glacial gravels (100 feet thick) and, thereafter, proceeded to excavate the solid rock to the depth of another 100 feet at least. Thereafter ensued a return to glacial conditions, and over the newly excavated valley was accumulated another sheet of gravels reaching an average thickness of eighty feet. Once more the glaciers retreated, accumulation ceased, and valley-erosion was resumed, the rivers cutting down through the second series of gravels into the solid rock as before, which they trenched to a depth of sixty or seventy feet. Then a third advance of the glaciers took place and a corresponding series of fluvio-glacial gravels was deposited—the upper surface of which now rises

much beyond the reach of the greatest river-floods of today. Similar evidence of interglacial erosion is met with in many other mountain-regions of middle Europe — in the Carpathians, the Riesengebirge, the Black Forest, the Vosges and central France. In the last-named region the evidence shows that during the time that separated two glacial epochs the rivers dug out valleys some 900 feet in depth.

Such are some of the facts which have led many observers to believe in the periodicity of glacial action. There are several other lines of evidence that lead to the same conclusion, but it is needless to discuss these here as I have treated them more or less fully elsewhere. All that I shall attempt at present is to sketch in outline the general succession of glacial and interglacial horizons which can be more or less clearly made out in Europe. To avoid confusion I shall give to each of these horizons a separate name.

I. SCANIAN.

The earliest glacial deposits of northern Europe occur in Skåne — the old division of southern Sweden — hence the provisional name I suggest. These indicate the former existence of a great Baltic glacier which overflowed the southern part of the Scandinavian peninsula from southeast to northwest. No glacial deposits have been recognized on this horizon elsewhere in northern Europe. It is most probable, however, that the Arctic-shell beds of Norfolk known as the Chillesford Clay and Weybourn Crag belong to this stage. To the same horizon I assign the first glacial epoch of which we have evidence in the Alpine Lands. At this stage the glaciers of that region filled all the mountain-valleys and in many cases deployed upon the "Vorländer," where their terminal moraines and associated fluvio-glacial gravels are still conspicuous. To the same epoch ought probably to be referred the ancient Diluvium of the plateaux of central France. According to Penck the snow-line in the Alpine Lands must have been depressed some 4000 feet below its present level.

II. NORFOLKIAN (OR ELEPHAS-MERIDIONALIS STAGE).

This stage is typically represented in northern Europe by the well-known "Forest-bed Series" of Norfolk. During the preceding epoch the North Sea was probably not less extensive than it is today—it even encroached upon what are now the maritime tracts of East Anglia. The "Forest-bed Series" of Norfolk points to the retreat of the North Sea from the southern area of that basin. Britain was at that time joined to the Continent and enjoyed a climate not less temperate than the present. The mammalian fauna included *Elephas meridionalis*, *E. antiquus*, *Hippopotamus*, *Rhinoceros etruscus*, *Machærodus*, etc. In the Alpine Lands the same stage is represented by the lignite-beds of Leffe, etc. (N. Italy), containing *Elephas meridionalis*, *Rhinoceros leptorhinus*, etc., and a flora indicative of more genial conditions than are now experienced in the valleys where those deposits occur. On the same horizon are the interglacial beds of Hötting in the valley of the Inn at Innsbruck—the remarkable flora of which similarly testifies to a warmer climate than the present. The so-called Upper Pliocene deposits of France, such as those of Mt. Perrier and St. Prest, belong most probably to this stage of the Glacial Period.

III. SAXONIAN.

To this horizon belong the accumulations of the epoch of maximum glaciation when the Scandinavian *mer de glace* invaded the low grounds of Saxony and the great glaciers of the Alps piled up the moraines of the "outer zone." The stage is well represented, in nearly all the mountain-ranges and elevated plateaux of the continent, by moraines and fluvio-glacial gravels—while heaps and sheets of rock-rubbish and breccia (pseudo-glacial accumulations) point to the action of severe climatic conditions at lower levels. Flood-loams were doubtless also abundantly distributed over the broad valleys and low-lying tracts of extra-glacial regions. But these cannot always be separated from the similar deposits of later glacial stages which must obviously have been deposited over the same tracts. To

the same stage ought to be referred those Pleistocene marine beds of Sicily which are charged with a northern fauna.

The Saxonian thus includes the "lower bowlder-clay" of the British Islands; the "lower diluvium" of Holland, central and southern Germany and central Russia; the ground-moraines and terminal moraines of the "outer zone" (Alpine Lands), and their associated gravels; the older moraines of many mountain tracts in middle and southern Europe; the lower breccias of Gibraltar and much of the "rubble-drift" of other regions.

IV. HELVETIAN (OR ELEPHAS-ANTIQUUS STAGE).

The interglacial deposits of this stage having been first detected in Switzerland suggest the term selected. The Helvetian includes a number of well-known deposits, some being marine, while others are of fresh-water and terrestrial origin. The flora and fauna are indicative of varying climatic conditions. Some of the British beds, for example, have yielded a northern and temperate flora, the mammals including mammoth, woolly rhinoceros and reindeer, while others contain the relics of temperate and southern forms, such as *Elephas antiquus*, *Rhinoceros leptorhinus*, *Hippopotamus*, etc. In like manner, the equivalent beds in middle Europe have yielded northern and temperate floras and faunas — the latter including mammoth, *Elephas antiquus*, Irish deer, horse, etc., while the flora betokens a more genial climate than now obtains but subsequently deteriorating. In central and southern Europe the Helvetian stage is characterized by a temperate flora and fauna — the latter marked by the presence of *Elephas antiquus*, *Hippopotamus*, *Rhinoceros Merckii*, mammoth, etc.

Amongst the more prominent members of the Helvetian group are the interglacial beds of the British area, as in the maritime tracts of the Moray Firth and the Irish Sea, in Lanarkshire, Ayrshire, Edinburghshire, etc.; the Hessle gravels of East Anglia; the beach-deposits of Sussex; the accumulations of Settle Cave, etc. On the Continent, we have certain marine and fresh-water interglacial beds occurring in the Baltic coast-lands;

the interglacial peat, etc., of Holstein, Rixdorf, Kottbus, Moscow, etc.; the lignites of Switzerland and Bavaria; certain beach-accumulations in northern France; the interglacial deposits of Cantal; and the marine terraces cut in the lower breccias of Gibraltar.

To the same horizon I would assign a considerable proportion of the Pleistocene river-deposits of the Thames, the Seine, the Rhine, etc., as well as many of the cave accumulations of western Europe. But to these and other Pleistocene deposits occurring in extra-glacial regions, reference will be made in the sequel.

V. POLANDIAN.

To this stage belong the glacial and fluvio-glacial accumulations of the minor Scandinavian *mer de glace*, and the corresponding deposits in the mountain tracts of central and southern Europe. The extreme limits reached by the minor ice-sheet have been only approximately ascertained, and cannot at present be represented by a hard-and-fast line. As the ice-sheet extended well into Poland, this has suggested the provisional name given to the stage.

The Polandian includes the "upper bowlder-clay" and associated fluvio-glacial deposits of the British Islands; the "upper diluvium" of central Germany, Poland, west-central Russia, etc.; and the ground moraines and terminal moraines of the "inner zone" (Alps) together with their accompanying gravels. Contemporaneous with these are certain valley moraines in other mountain regions; as also rubble-drifts and alluvial accumulations in extra-glacial tracts.

That the Polandian forms a clearly marked stage is shown not only by the circumstance that it is separated from the Saxonian by the intervening Helvetian, but by the notable fact that the path followed by the minor *mer de glace* did not quite coincide with that pursued by the preceding greater ice-sheet. Thus in southern Scotland the track of the later ice-flow crosses that of the former in some places nearly at right angles, and the same is the case upon the Continent. The maximum ice-sheet,

for example, flowed approximately south across Denmark and the southern Baltic area into Holland and north Germany, while the later *mer de glace* had a more westerly trend.

VI. NEUDECKIAN.

The deposits on this horizon are best developed in the coast-lands of the southern Baltic. They are partly of marine and partly of fresh-water origin, and are intercalated between the so-called "lower" and "upper" bowlder-clays of that region. The general aspect of the fauna is temperate—certainly not Arctic. The highest level to which the marine beds have been traced is 114 meters, at Neudeck near Freistadt in west Prussia. Probably many of the older alluvia overlying the Polandian in regions over which the succeeding Mecklenburgian does not extend ought to be assigned to the Neudeckian stage.

VII. MECKLENBURGIAN.

The most notable deposits belonging to this stage are the ground moraines and terminal moraines of the last great Baltic glacier. These reach their southern limits in Mecklenburg. Contemporaneous accumulations are the bowlder-clays and terminal moraines of the large valley-glaciers and district ice-sheets of the British Islands, and the terminal moraines occurring in the great longitudinal valleys of the Alps (= "first post-glacial stage of glaciation" of Penck and others).

To the same stage are assigned the *Yoldia*-beds of Scandinavia, and the 100-foot terrace of Scotland with its Arctic marine fauna. Here also come most of the Arctic plant-beds of the British Islands, as well as those which underlie the older peat bogs of Denmark, south Sweden, etc.

VIII. LOWER FORESTIAN.

This stage embraces the deposits of the great fresh-water lake of the Baltic area (*Ancylus*-beds); the lower buried forests occurring under the peat-bogs of northwest Europe generally; and the *Littorina*-beds of Scandinavia in part. No deposits on this horizon have yet been recognized in the Alpine Lands. The

evidence as to climatic and geographical conditions furnished by the Lower Forestian of northwest Europe is abundant and clear. The wide horizontal and vertical distribution of forest trees betokens not only a more extensive land-surface than the present, but a better climate. The fauna of the *Littorina*-beds also indicates the former existence of more genial conditions in our seas.

IX. LOWER TURBARIAN.

This stage is most characteristically represented by the peat which immediately overlies the lower forest-bed of our turbaries; by the calcareous tufas of Scandinavia, etc.; by the Carse-clays and raised beaches of Scotland, and the Scandinavian *Littorina*-beds in part, and by valley-moraines and corrie-moraines. The invasion by the sea which marked the passing of the Lower Forestian stage was continued into the Lower Turbarian stage. The climate at the same time became more humid and colder—hence the restriction of forest-growth and the increase of snow-fields. In Scotland glaciers here and there came down to the sea and dropped their moraines upon the beach-deposits—the large majority, however, terminated inland, some of these being true valley-glaciers while a larger number were corrie-glaciers. The general distribution of the moraines indicates a snow-line ranging between 2000 and 2600 feet. In Norway the glaciers were correspondingly of more importance—the position of their moraines pointing to a snow-line in South Norway of 2400 feet or thereabout. In the Alpine Lands this stage appears to be represented by the terminal moraines of the so-called "second post-glacial stage."

X. UPPER FORESTIAN.

Overlying the Lower Turbarian of northwest Europe we come again and again upon a second buried forest. The flora and fauna of this stage denote temperate and drier conditions; while the distribution of the forest-bed plainly indicates a formerly wider land-surface, but one not apparently so extensive as that of the Lower Forestian. In Scotland the upper forest-bed distinctly overlies the Carse-clays, etc., of the preceding stage.

XI. UPPER TURBARIAN.

The upper forest-bed is in its turn overlaid by peat — a succession seen in the turbaries over a vast region. Followed from the interior to the coast-lands in Scotland this peat is found passing under the lower raised beaches. The Upper Turbarian was therefore marked by a new advance of the sea. No moraines rest upon these later beaches, and this last epoch of submergence cannot therefore be directly connected with any of the glacial deposits of the interior. It is remarkable, however, that in the highest mountain-groups of Scotland we encounter not only the terminal moraines of the Lower Turbarian, but another and later series, the presence of which implies a snow-line at 3500 feet. In mountains which are under that elevation the lower series of moraines alone puts in an appearance. The inference, therefore, is that the higher-level moraines bear the same relation to the peat-bogs and raised beaches of the Upper Turbarian as the lower-level moraines do to the corresponding accumulations of the Lower Turbarian. This stage must doubtless be represented in Norway by similar moraines at high levels — indeed these are well-known to exist, although they have hitherto been looked upon as simply marking pauses in the retreat of the larger ice-flows of an earlier stage. In the eastern Alps no third "post-glacial stage" of moraines has been recognized, but that is because these mountains have not the requisite elevation. It is in the western Alps that traces of such a stage must be sought for, and I venture to predict that they will yet be recognized.

I should like now to add a few remarks on the methods followed in this attempt to classify and interpret the complex accumulations of the glacial period. In working out the geological structure of a district we all know how helpful it is to discover some well-marked datum-line — some horizon, whose position is fixed, and to which constant reference can be made. Having been assured that interglacial epochs broke up the continuity of the Ice Age, it was obviously important to ascertain

which of the glacial accumulations represented the epoch of maximum glaciation. Here, fortunately, there was no difficulty. For many years geologists have agreed that the lower bowlder-clay of Britain and the corresponding lower diluvial accumulations of the Continent are the products of the epoch of greatest cold. It was not going beyond the limits of cautious induction to infer that the epoch of maximum glaciation in northern Europe must have been contemporaneous with the same epoch in the Alpine Lands and other mountainous districts on the Continent. Nothing, I should think, can be more probable than that the diluvial accumulations of the most extensive Scandinavian *mer de glace*, which advanced into Saxony, must be on the same horizon as the moraines of the outer zone at the foot of the Alpine Lands. We may consider the Saxonian, then, a well-determined horizon. The next step was to ascertain what relation the deposits of that stage bore to other glacial accumulations. In Britain we have long held that our lower bowlder-clay is the product of the first and greatest glacial epoch, for hitherto no older deposit of the kind has been recognized in these islands. But although that be true for Britain it is not so for Scandinavia. In southern Sweden a still older bowlder-clay exists — the groundmoraine of a former great Baltic ice-sheet, which overflowed Scania from southeast to northwest — a direction at right angles to that followed by the *mer de glace* of maximum glaciation. Again, in the Alpine Lands, as Professor Penck and his coadjutors have shown, the epoch of maximum glaciation was similarly preceded by a yet earlier ice age of very considerable severity — the glaciers descending to the low grounds, but not flowing so far as those of the glacial epoch that followed. Further, it has been ascertained that between the groundmoraines of those two successive epochs there intervene fossiliferous deposits — the plants of which denote a much more genial climate than is now experienced in the valleys of the Alps. Moreover, the amount of contemporaneous valley-erosion demonstrates that this interglacial stage was one of prolonged duration. It was only reasonable to infer that such climatic

changes could not have been confined to Scandinavia and the Alps. If interglacial and glacial conditions obtained in those regions it was obvious that our own islands must have been contemporaneously affected. And the evidence of such climatic changes is found, as I think, in the "Weybourn Crag" and "Chillesford Clay" and the overlying "Forest-bed Series" of Norfolk—the former containing a well-marked Arctic marine fauna, while the latter is charged with the relics of a temperate flora, as well as of temperate and southern mammalian forms. To what extent Britain may have been glaciated when the Arctic shell-beds in question were being deposited we can only conjecture—for the later ice-sheet of maximum glaciation made a clean sweep of almost everything. Were it not for the presence of these marine deposits there would be no evidence in Britain to show that the epoch of maximum glaciation was not the earliest of the series. But the existence of a great Baltic glacier, of an Arctic fauna in the North Sea, and of enormous snow-fields and glaciers in the Alps, implies the contemporaneous existence of considerable snow-fields and glaciers in Britain. It may be safely inferred, therefore, that the Saxonian stage, or epoch of maximum glaciation, was preceded by an earlier but less severe glacial epoch (Scanian stage), the genial Norfolkian stage separating the one from the other.

The next succeeding interglacial and glacial horizons have long been recognized. It is generally admitted by European glacialists that the epoch of maximum glaciation was followed by a more or less prolonged interval of genial temperate conditions. In most glaciated regions the Helvetian stage is represented by fossiliferous deposits, which separate the diluvial deposits in which they occur into an upper and a lower series. So well marked is this division in northern Germany, that long before the significance of interglacial deposits dawned upon geologists, an upper and a lower Diluvium had been recognized. The flora and fauna of the Helvetian stage surely indicate conditions not less temperate than the present. Indeed, the plants occurring upon this horizon in middle Europe imply for the

interior of the continent a climate even more genial than that which now obtains. Further, the long duration of the Helvetian epoch is shown by the extensive valley-erosion then accomplished. We may conclude that, at the climax of this particular interglacial stage, the snow-fields and glaciers of Europe were of no more importance than they are in our own day.

If this conclusion be well sustained it is obvious that the ice-sheet of the Polandian stage was separate and independent, and not a mere phase of the greater Saxonian *mer de glace*. The latter had for a long time disappeared before the minor ice-sheet came into existence—and the independence of the latter is still further shown by the fact that its path differed in some important respects from that followed by the earlier ice-flow. In Saxonian times the Baltic basin had little influence upon the general direction of the *mer de glace*, while the course of the succeeding Polandian ice-sheet was obviously to a large extent controlled by that great depression. And similar remarkable differences in the directions followed by the two ice-sheets have been detected in Britain.

From the Scanian to the Polandian the succession is easily read, but from this stage onwards the evidence is rather harder to follow. My own investigations in Britain led me long ago to conclude that climatic oscillations had continued to take place after the formation of our upper bowlder-clay. I found, for example, that subsequent to the retreat of the minor *mer de glace*, underneath which that upper till had accumulated, there supervened an epoch of district ice-sheets and valley-glaciers. The evidence showed clearly enough that the upper till had been partly ploughed out and large terminal moraines piled upon its surface by a still later series of ice-flows. But as no interglacial beds have hitherto been detected between the moraines in question and the underlying bowlder-clay I could not be sure that the epoch of large local glaciers had been separated from that of the Polandian stage by any long interval. It seemed possible that the valley-glaciers were merely the degenerate successors of

the minor *mer de glace*, which after retreating had again advanced, before they finally vanished. Nevertheless it was obvious that this later advance could not have been a slight temporary movement, but must have endured for a considerable time, so as to allow of much glacial erosion and the heaping-up of immense quantities of morainic rubbish, and the deposition of great terraces of fluvio-glacial gravels. These conditions I found characterized all the mountain areas of the British Isles. It is to this epoch, in fact, that the final grinding-out of our more conspicuous lake-basins must be assigned. The relation borne by the district and valley-moraines to the Arctic shell-beds was also significant. These latter overlie our upper bowlder-clay and are of later age than the Kames and Eskers of our lowlands. They show in short that, after the melting of the minor ice-sheet, submergence of the coast-lands ensued, to the extent of at least 100 feet below their present level. They further show that this submergence was contemporaneous with the existence of the district ice-sheets and valley-glaciers — for the morainic gravels of the latter merge with the deposits of the 100-foot terrace; and here and there moraines are associated with the latter. Not only so, but it is obvious that many of the large glaciers descending to the sea along the west coast of the Scottish Highlands, filled the fiords and prevented the formation there of marine deposits. Thus the 100-foot terrace is well developed upon the open sea coast, but suddenly dies off when the fiords are entered. In the basin of Loch Lomond, again, the glacier ploughed out certain shelly clays so that its groundmoraine is charged with the débris of marine organisms. It is noteworthy in this case that the fauna of the shell-beds thus largely demolished does not indicate Arctic conditions — the species are for the most part living British forms, while the fauna of the undisturbed shelly clays of the 100-foot beach is decidedly northern and Arctic.

From the evidences thus baldly stated the following conclusions seemed probable:

1. The retreat of the minor ice-sheet was followed by submergence to 100 or 150 feet, and the sea eventually became ten-

anted by a fauna not essentially differing from that of the present, but the climate may have been somewhat colder.

2. Recrudescence of glacial conditions supervened, and great valley-glaciers descended from the mountains, filling up the fiords, and ploughing out preëxisting marine deposits. The climate at that time was Arctic—as shown by the character of the fauna in the undisturbed shelly-clays.

It seemed to me quite clear, then, that the 100-foot beach and the contemporaneous morainic accumulations indicated a distinct stage of the Glacial Period. But it was not quite so evident that this stage had been separated from that of the minor *mer de glace* by a well marked interglacial epoch. It became necessary, therefore, to consider the glacial succession on the Continent for the purpose of ascertaining what light that could throw on the problem suggested by the British deposits. The geologists of Scandinavia, Finland and north Germany had discovered the existence of certain great terminal moraines, which, as De Geer showed, must have been accumulated by a great Baltic glacier. These moraines were considered generally to mark a pause in the retreat of the minor *mer de glace*—that, namely, of the Polandian stage—and it struck me as not improbable that in them I had the equivalents of the similar accumulations of our islands. Outside of the great moraines there could be no doubt about the occurrence of two bowlder-clays—those, namely, in the Saxonian and Polandian stages. Between the moraines and the shores of the Baltic, however, not only two, but three, or even, in some places, four bowlder-clays are known to occur. As we might have expected, however, the occurrence of two or of one only is most usual. German geologists have classified the drift deposits of the Baltic coast-lands in the same way as those of the Elbe valley—recognizing, as in that region, a lower and an upper Diluvium. In short, they consider the upper bowlder-clay of the Baltic coast-lands to be continuous with the upper bowlder-clay that stretches south from the great moraines of the Baltic ridge into the valley of the Elbe. In this view the lower bowlder-clay of the Baltic coast-lands is on

the same horizon as the bowlder-clay of the Saxonian stage. On comparing the bowlder-clays of the Baltic lands with those that lie outside of the great terminal moraines it seems to me that this correlation cannot be sustained. The lower bowlder-clay of Holland, for example, has been laid down by a *mer de glace* which flowed in a general southerly direction. But this does not hold true of the so-called lower bowlder-clay of Denmark and Schleswig-Holstein. On the contrary, the two bowlder-clays which occur together in the Baltic coast-lands of that region have both been laid down by ice streaming from east to west out of the Baltic basin. The lower of these bowlder-clays extends across the Cimbric peninsula to the North Sea, while the upper is margined by the great terminal moraines.

The former cannot be correlated with the lower bowlder-clay of Holland, etc., but must occupy the horizon of the Polandian. And this conclusion is further sustained by the fact that the so-called lower bowlder-clay of central Holstein is underlaid by an older groundmoraine, from which it is separated by abundant fossiliferous deposits belonging to the Helvetian stage. In short, the lower bowlder-clay of the Baltic coast-lands is on the horizon of the Polandian stage, while the upper bowlder-clay of the same regions is the groundmoraine of the great Baltic glacier, whose utmost limits are marked by the terminal moraines of the Baltic Ridge.

So far, then, the evidence derived from the Continent points in the same direction as that supplied by the equivalent deposits in Britain. But it carries us further, for in the Baltic coast-lines the youngest bowlder-clay (Mecklenburgian) is separated from the underlying bowlder-clay (Polandian) by an abundant series of fresh-water and marine deposits—some of which indicate cold conditions, while others imply a climate not less temperate than the present. Here, then, is the link in the chain of evidence which we miss in Scotland. If a more or less prolonged temperate interval (Neudeckian) separated the Polandian and Mecklenburgian epochs on the Continent, the same must have been the case in Britain.

Having arrived at the conclusion that a distinct glacial epoch is represented in northern and northwestern Europe by the great Baltic glacier and the district ice-sheets and valley-glaciers of Britain, we might well expect to meet with evidence of a contemporaneous advance of the Alpine glaciers. The three-fold grouping of terminal moraines and associated fluvio-glacial gravels in the Alpine "Vorland" represents, as we have seen, three successive glacial epochs — the Scanian, the Saxonian and the Polandian. Entering the mountains by the main valleys, no conspicuous terminal moraines are encountered for a long distance. Eventually, however, these make their appearance. They are of very considerable dimensions and indicate a time when all the great longitudinal valleys contained large trunk glaciers — none of which, however, reached within many miles the limits attained by the glaciers of the preceding third glacial epoch. The moraines now referred to constitute Professor Penck's "first post-glacial stage," when the snow-line would seem to have been 3000 feet lower than now. So far as I am aware, there is no evidence of interglacial conditions having supervened before the advent of these early "post-glacial glaciers." The moraines in question might simply indicate a pause in the retreat of the great glaciers of the third glacial epoch. It is inconceivable, however, that the very considerable climatic changes which are evidenced by the Neudeckian and Mecklenburgian stages of northern Europe should not have affected the Alpine Lands. And it is, at all events, probable that the moraines of the "first post-glacial stage" are the equivalents of the great moraines of the Baltic Ridge, and the products, therefore, of a separate and distinct glacial epoch. The absence of any Alpine representatives of the Neudeckian interglacial stage need not surprise us — for, as I shall show presently, the occurrence of such deposits in mountain-valleys must always be exceptional.

The stage which I have termed Lower Forestian is one of the most clearly marked in the whole Pleistocene series. In Britain and Scandinavia its position with reference to underlying and overlying accumulations is precisely similar. An Arctic

flora occupied the low grounds of both countries during the decay and disappearance of the great Baltic glacier and its British equivalents. To that eventually succeeded a vast forest-growth the relics of which underlie our oldest peat-bogs. The lower forest-bed rests, in short, upon the glacial, fluvio-glacial and marine deposits of the Mecklenburgian stage. At the climax of the Lower Forestian a wide land-surface obtained in northwestern Europe, and the Baltic became a fresh-water lake. Eventually, submergence ensued before those genial conditions had passed away—the marine fauna evidencing warmer waters than now lave the coasts of northwestern Europe.

The next stage (Lower Turbarian) is represented typically in Scotland by the peat which overlies the lower forest-bed and by the raised beaches underneath which the Lower Forestian passes out seawards. The same succession occurs in Scandinavia. Thirty years have elapsed since I first pointed out the significance of this old buried forest and its overlying mantle of peat, and the conclusions I then arrived at have since been supported by the independent researches of Professor Blytt and other botanists and geologists abroad. In subsequent years I had succeeded in gathering much additional evidence. I found that the raised beaches and estuarine deposits which overlie the lower buried forest in our maritime districts, when they are followed inland, eventually pass into fluvio-glacial gravels, and I adduced further evidence to show that during the formation of these beaches and the lower peat of the inland tracts small valley-glaciers existed in the Scottish Highlands. The researches of the Geological Survey have since then shown that these glaciers came down to the sea here and there in the west Highlands and dropped their moraines upon the deposits of the fifty-foot beach. These glaciers I described in *Prehistoric Europe* as "post-glacial glaciers"—meaning by that, glaciers which had come into existence after the disappearance of the minor *mer de glace*. The character of the flora of the lower forest-bed and the wide horizontal and vertical range of the trees, and the facies of the fauna of the *Littorina*-beds of the same stage alike

indicate more genial conditions than now obtain in northwest Europe. During the climate of Lower Forestian times it is not at all probable that permanent snow-fields of any kind could have existed in Britain. The glaciers of the succeeding Lower Turbarian epoch were not the attenuated descendants of the great valley-glaciers and district ice-sheets but entirely independent of and unrelated to these.

In southern Norway the great moraines of the Mecklenburgian stage skirt the coast-line. Considerably further inland we encounter another series of large terminal moraines, constituting Dr. Hansen's "epiglacial stage." These moraines I take to be on the same horizon as those of the Lower Turbarian in Scotland. They indicate a snow-line in southern Norway at about 2400 feet, and this corresponds fairly well with the snow-line in Scotland which, during Lower Turbarian times, averaged a height of 2500 feet.

In the Alpine Lands, after leaving the moraines of the "first post-glacial stage," we meet with no more accumulations of the kind until we penetrate far into the lateral valleys, and there another series of conspicuous moraines occurs, forming Penck's "second post-glacial stage." These indicate a depression of the snow-line of about 1600 feet.

The cold, humid conditions of the Lower Turbarian stage were followed by a more genial and drier climate, the evidence of which is abundantly supplied by the upper forest-bed in the peat-bogs of northwest Europe. As this forest-bed with its overlying peat passes out to sea underneath the youngest raised beaches of Britain and the opposite coasts of the Continent, we infer that in Upper Forestian times the land was of wider extent than now. In the Upper Turbarian we in like manner read the evidence of a subsequent relapse to wet and ungenial conditions—the overlying raised beaches indicating further that these conditions were accompanied or followed by partial submergence. To this stage I assign the relatively small moraines which are restricted to the highest mountain-groups in Scotland—the position of these indicating a snow-line at about 3500

feet. Here, however, the evidence lacks the precision of that supplied by the Lower Turbarian. During that stage moraines were deposited upon the fifty-foot beach which overlies the Lower Forestian. But none of the latest high-level moraines approaches the coast-line — we meet with no moraines resting upon the twenty-five-foot beach.

In the mountain valleys of Norway conspicuous moraines occur at higher levels than those which I have correlated with the Lower Turbarian moraines of Scotland, and some of these are probably contemporaneous with the moraines of the Upper Turbarian in Scotland. In the eastern Alps no moraines corresponding to the highest Scottish series are met with, but in the loftier regions of the western Alps they will probably be found when they are looked for.

It is well worthy of note that the glaciers of the Lower and Upper Turbarian stages endured long enough to allow of the erosion of many small valley and corrie-basins. Each glacial epoch indeed was marked by the formation of lake-basins — some excavated in solid rock, others dammed by morainic accumulations. In Scotland the larger valley-lakes date their origin to the epoch of district ice-sheets, etc. (Mecklenburgian stage); a second series of relatively small valley-basins, and innumerable corrie-basins came into existence during the Lower Turbarian stage, while a third set of corrie-basins and a few high-level valley-basins are the beds of the vanished glaciers of Upper Turbarian times.

In every region which has been subjected to glacial action two areas are recognizable — namely a central area of erosion and a peripheral area of accumulation. In the former bare rock predominates and only patchy, interrupted deposits of morainic origin occur — in the latter the products of glacial erosion are accumulated, and the solid rocks are largely concealed. Hence it is in the latter areas that interglacial deposits are most likely to have been preserved. It is further obvious that if one and the same region has experienced a succession of glacial and interglacial conditions, it is rather the accumulations of the later

than those of the earlier epochs that will present themselves. The distribution of the interglacial and glacial deposits of Europe shows this clearly enough. Not a trace of the Scanian bowlder-clay has been recognized in Britain, but it is probably represented by the lowest-lying bowlder-clay of the south Baltic coast-lands. Again but for the Norfolkian beds we should never have known that a genial interglacial epoch followed after the passing of the Scanian stage. The area of glacial erosion was so enormously extended during Saxonian times that preëxisting superficial beds in northern and northwestern Europe were almost completely obliterated. Under the Polandian ice-sheet great erosion likewise took place, but the area affected was not quite so extensive. Hardly a trace of the Scottish lower bowlder-clay (Saxonian) occurs in the mountain regions, it is only in the low grounds that it puts in an appearance—becoming more and more conspicuous as the peripheral areas occupied by the minor *mer de glace* (Polandian) are approached. The same tale is told by the corresponding deposits on the Continent. In a word it is in the peripheral areas of glacial accumulation that the deposits of the immediately preceding interglacial epoch are most abundantly preserved. If this be true of the Helvetian and Polandian, it is true also of the Neudeckian and Mecklenburgian stages. The Neudeckian beds are met with chiefly in the southern coast-lands of the Baltic. So again we cannot expect to meet with plentiful relics of the Lower Forestian stage in the mountain valleys which were subsequently occupied by the local glaciers of the Lower Turbarian. It is only in places where these glaciers descended to the low grounds or entered the sea that they were likely to override interglacial deposits and to cover these with their moraines. And this, as we have seen, is just what happened in Scotland—the fifty-foot raised beach clearly underlies the terminal moraines of Lower Turbarian times.

Similar phenomena confront us in the Alpine Lands. It is in the "Vorländer" and the lower reaches of the great mountain valleys that the successive glacial and interglacial stages are

best represented. Exceptionally, as in the case of the Hötting beds at Innsbruck, interglacial beds have been preserved under the moraine of the great ice-flow of maximum glaciation. But the beds in question had become indurated by infiltration and converted into solid rock before the advent of that great glacier, and consequently were better able to resist erosion.

It is obvious that the accumulations of glacial and interglacial times which occur over so wide a region in northern and northwestern Europe, and are so well represented in the mountain lands further south, must have their representatives in what we may term extra-glacial tracts. I have spoken of the Norfolkian beds of East Anglia as being the only representatives of that stage that we can certainly recognize in northern Europe. But it seems to me most probable that the fossiliferous deposits which underlie the lower bowlder-clay (Saxonian) of middle Germany occupy the Norfolkian horizon. Be that as it may, we cannot doubt that each interglacial stage must have its equivalent amongst the Pleistocene accumulations of non-glaciated regions. This can be demonstrated in the case of the Lower Forestian stage. It has long been known that a great forest-growth characterized northwestern Europe in what is usually termed the "post-glacial epoch," and that partial submergence of the land subsequently ensued. Now the deposits of this so-called "post-glacial stage" are overlaid in Scotland by a series of moraines—the position of which indicates that the snow-line stood at an average elevation of 2500 feet. The flora and fauna of the Lower Forestian, on the other hand, denote a climate even more genial than the present. Hence the Lower Forestian, capped as it is by glacial accumulations, obviously occupies an interglacial position. In a word, the lower peat-bed occurring under the peat-bogs of northwest Europe outside of the regions reached by the glaciers of the Lower Turbarian stage, is the product of an interglacial epoch, to which succeeded an epoch of manifestly colder conditions. On the same principle and for similar reasons I would assign to interglacial horizons all the Pleistocene alluvial and cave deposits of extra-

glacial tracts which have yielded relics of interglacial floras and faunas; while those containing the remains of northern and Arctic forms I look upon as representatives of the several glacial stages.

Thus I would range under the head of Norfolkian not only the "Norwich Forest-bed series" and the equivalent interglacial beds of the Alpine Lands, but the so-called "pre-glacial beds" underlying the Saxonian diluvial formation of middle Germany, etc., together with the *Elephas-meridionalis* beds of France, Italy, etc. The subsequent glacial and interglacial stages must each have representatives in extra-glacial tracts, and I am sanguine enough to believe that the detailed correlation of the former with the latter will some day be accomplished. Already, indeed, progress has been made in this direction. Distinct stages in the Pleistocene alluvia have been recognized not only by means of their organic remains, but by working out their relation to the fluvio-glacial terraces that extend outwards from glaciated regions. In this way it has been proved that no small proportion of the ossiferous and palæolithic river-gravels are on the horizon of the Helvetian interglacial stage. So again with regard to the Löss, recent researches have shown that the areas occupied by this deposit have been tenanted successively by tundra, steppe, and forest-faunas. And, further, as Penck and others have demonstrated, the Löss is not the accumulation of one single epoch, but must be relegated to different stages of the Glacial Period.

Apart altogether from the stratigraphical relations of the Pleistocene alluvia and cave-accumulations to the fluvio-glacial and glacial deposits, it has long been recognized that the organic remains of the former are indicative of climatic oscillations. Did no glacial and interglacial beds exist, we should yet infer from a study of the Pleistocene alluvia and cave-accumulations that great changes of climate must have taken place during their formation. It is clear, in a word, that the Pleistocene deposits of extra-glacial and glaciated regions are merely portions of one and the same geological series—they are of con-

temporaneous origin. Thus, when the former are followed towards regions of glacial accumulation they eventually disappear under bowlder-clay or other diluvial deposits, or else they are found occupying interglacial positions. It was this remarkable distribution that first suggested to me, many years ago, that these ossiferous alluvia could not be of post-glacial age, as was at that time generally supposed.

In raising the number of glacial epochs from two or three to five or six I am aware that I run the risk of exciting prejudice. If it be hard to conceive of a succession of three glacial epochs, it will seem harder still to admit the possibility of double that number having supervened in Pleistocene times. We are so much the slaves of terminology, that had I restricted the term *epoch* to the first three cold stages, and merely described the last three as indicating *episodal* climatic oscillations in post-glacial times, my conclusions would probably have assumed a less disturbing guise. But the evidence was quite antagonistic to such a division. Before I had ascertained that the district ice-sheets, etc., of Britain (Mecklenburgian stage) represented a distinct glacial epoch—so long as I believed them to be merely the attenuated descendants of the minor *mer de glace* (Polandian stage)—it was possible to hold that the Glacial Period closed with the final disappearance of that particular ice-sheet. Thus the deposits of the 100-foot beach were formerly classed by me as "late glacial"—all the overlying accumulations being included in the "post-glacial and recent series." Some thirty years ago I had adduced evidence to show that oscillations of climate had supervened in post-glacial times—a view which was suggested by the occurrence of successive forest-beds in the peat-bogs of northwestern Europe. The researches of subsequent years tended strongly to confirm that view, and in *Prehistoric Europe* (1881) I showed that upon the decay of the great forests which occupy the bottom of the peat-bogs, the land was partially submerged, the climate became colder and more humid, and snow-fields and valley-glaciers reappeared in the Scottish Highlands These I designated "post-glacial glaciers." I had no thought at

that time of including this recrudescence of glaciation as a phase of the Glacial Period proper. I then considered the closing stage of the Ice Age to be represented by the groundmoraine of the minor *mer de glace* and by the moraines of retreat dropped by the great valley-glaciers into which that ice-sheet, as I believed, was finally resolved. The contrast between the *mer de glace* of our upper bowlder-clay, and the terminal moraines of "post-glacial" times was so great that it would have been absurd to include the latter in the Glacial Period proper. The subsequent discovery by Penck of "post-glacial" moraines in the Pyrenees, and the recognition of similar "post-glacial" stages in the Alpine Lands, tended to confirm me in the view that the Glacial Period closed with the disappearance of the vast ice-sheet underneath which our upper bowlder-clay was accumulated. But after I had learned that the district ice-sheets of Britain and the last great Baltic glacier belonged to an independent epoch, separated from the preceding cold epoch by well-marked interglacial conditions of long duration, it became necessary to reconsider the question of classification. The intercalation of the Neudeckian and Mecklenburgian stages at once broke down the climatic barrier, if I may so speak, that seemed at one time to separate glacial from "post-glacial" times. The great contrast between the two no longer exists. What I find is a succession of glacial and interglacial stages, beginning with the Scanian and terminating with the Upper Turbarian. The climax of glacial extension was reached in Saxonian times, after which each cold stage diminished continuously in importance. In like manner the earliest interglacial epoch appears to have been the most genial, each successive epoch approximating more and more closely to existing conditions. In a word, the climates of the later glacial and interglacial phases were less contrasted than those of the earlier stages of the series.

But it may be urged that the earlier climatic stages being so much more pronounced than those of later times, they alone should be considered of epochal importance. Well, much depends upon what we imply by the term epoch. For myself I

use it simply as a vague term signifying a relatively long lapse of time. I do not think we have quite unequivocal evidence to show that any one of these epochs was longer or shorter than another. For aught that we can tell all may have been of equal duration. One is apt to infer that the enormous erosion and accumulation evidenced by the Saxonian implies a much longer time than the corresponding work accomplished, say, in the Lower Turbarian epoch. But we may quite well be mistaken in our inference. A horse will do much more work in an hour than a man can accomplish in the same time. So the vast ice-sheets and glaciers of the Saxonian stage, in the work they were able to perform, must necessarily have surpassed the comparatively insignificant ice-flows of a later date. But it is obvious that the erosion of a rock-basin 600 feet deep and twenty-five miles long need not have occupied more time than was required for the excavation of a basin hardly a mile in length and only a few yards in depth. Again, the Saxonian and Polandian bowlder-clays and fluvio-glacial gravels far surpass in importance those of the Mecklenburgian stage, but he would be a rash geologist who should maintain that the thicker and more extensive accumulations necessarily took the longest time for their formation. I am not aware of any evidence that would compel me to infer that the small local glaciers of the Lower Turbarian did not exist for as long a space of time as their gigantic predecessors of earlier glacial epochs. Once more, if we take into consideration the many complex climatic and geographical changes and the several migrations of flora and fauna which characterized the later phases of the Glacial Period, we shall hesitate before concluding that the Mecklenburgian and succeeding stages are less entitled to be classed as epochs than the more strongly contrasted stages that preceded them. And similar remarks apply to the interglacial stages. I do not know how we are to estimate the relative duration of each particular genial epoch. It can be shown that great valley-erosion took place during the earlier interglacial stages; and the persistence of these epochs is still further indicated by the depths to which surface-weathering

penetrated. If the epigene agents of change worked no more actively then than they did in later interglacial times or than they do in our own day, we should be led to infer that the earlier were of much longer duration than the later stages. But I doubt whether that inference would be justifiable. Such evidence as we have seems to indicate that the climates of the earlier interglacial stages were warmer and more humid than those of later epochs—and this means more active weathering and more energetic fluviatile erosion. If we base our estimate of the duration of the earlier interglacial epochs upon the present rate of erosion and accumulation, then doubtless we shall be led to conclude that these earlier stages were more protracted than the later. But it would seem more reasonable to take the latest interglacial epochs—those, namely, which approached most nearly to existing conditions—and endeavor to measure the duration of these by reference to the present rate of erosion. If we could ascertain approximately the time required for the erosion and accumulation which took place during the Lower or the Upper Forestian stage we should perhaps have a better index to the duration of interglacial epochs generally. In a word, the present rate of epigene action cannot be much less than that of late interglacial times, but it must have been considerably exceeded by that of earlier interglacial stages.

For ready reference I append a tabular statement of the glacial succession in Europe:

EUROPEAN GLACIAL AND INTERGLACIAL STAGES.

XI.	Upper Turbarian	=	Sixth Glacial Period.
X.	Upper Forestian	=	Fifth Interglacial Period.
IX.	Lower Turbarian	=	Fifth Glacial Epoch.
VIII.	Lower Forestian	=	Fourth Interglacial Epoch.
VII.	Mecklenburgian	=	Fourth Glacial Epoch.
VI.	Neudeckian	=	Third Interglacial Epoch.
V.	Polandian	=	Third Glacial Epoch.
IV.	Helvetian	=	Second Interglacial Epoch.
III.	Saxonian	=	Second Glacial Epoch.
II.	Norfolkian	=	First Interglacial Epoch.
I.	Scanian	=	First Glacial Epoch.

JAMES GEIKIE.

THE CLASSIFICATION OF AMERICAN GLACIAL DEPOSITS.

THE admirable delineation of the glacial deposits of Europe presented by Dr. Geikie in the foregoing paper invites a brief sketch of the American series for purposes of comparison.[1]

Our knowledge of the formations that were deposited during the advancing stages of the glacial period in America is extremely imperfect. Owing to the erosions of the overriding ice and the burial of the residue it is likely always to remain meager. There have been found, however, here and there, remnants of drift which have the appearance of superior age and of separateness from the overlying deposits, and which may therefore represent the accumulations of the earlier stages of the glacial period, but none of these seem as yet entitled to distinct recognition. We would appear, therefore, to have nothing which can be correlated with confidence with the Scanian horizon of Europe, as defined by Dr. Geikie.

A similar observation is to be made respecting the deposits of a stage possibly equivalent to the Norfolkian. In some localities beds of peat and vegetal débris, with accompanying earthy deposits, have been found underneath the lowest drift at the points in question, but I am not aware that there is any specific ground for connecting them immediately with the glacial period. It can simply be said of them that they were accumulated earlier than

[1] In the recent edition of "The Great Ice Age," an outline of the American glacial deposits was given to which the writer begs to refer for some characterizations of the members of the series here omitted or abbreviated. In that sketch the names Kansan, East Iowan and East Wisconsin were given to the three leading till sheets, as at present known, and the Toronto fossil beds were recognized under that name as an important interglacial deposit. Other interglacial deposits were not named, nor the latest members of the glacial series, which would be necessary to carry out a complete parallelism with the elaborate series of Dr. Geikie. Mr. Upham has made the suggestion that the terms East Iowan and East Wisconsin be abbreviated to Iowan and Wisconsin, which is cheerfully accepted, so far as it may be done without danger of misunderstanding.

the earliest known glacial invasion, but whether the accumulation was immediately antecedent (and so contemporaneous with some of the advancing stages of glaciation, or with some of the deglaciation stages that may have interrupted the advance), or whether it was more distantly antecedent, is an altogether open question. The perishable nature of such deposits offers some presumption that they were not very greatly antecedent to the maximum ice invasion, and, to that slight extent, offers a presumption that they were contemporaneous with the earliest stages of the glacial period in the larger application of the term.

The Kansan formation (=*Saxonian ?*).—The earliest formation which has been worked out into sufficient definiteness to merit specific recognition in the United States is an expansive sheet which reaches southward nearly to the junction of the Ohio and the Mississippi and southwesterly beyond the Missouri. The term Kansan has been applied to it because of its great extent in the direction of the arid plains and because it appears in the State of Kansas free from complications with other formations. It consists essentially of a sheet of till with associated assorted drift. Only the assorted material which was essentially contemporaneous with the till is here included. That which overlies it and was not formed at the same time is referred to the succeeding horizon.

There is a striking similarity between the Kansan formation and the Saxonian of Dr. Geikie. They both alike represent the greatest extension of the ice sheet. They are alike in terminating in an attenuated and worn border, in the main. They are neither corrugated by great peripheral moraines, as a rule, nor by longitudinal drumloidal ridges, nor, in general, by great esker systems, or kame aggregations. None of these features are entirely absent, but they have a relatively inconspicuous development. The relations of the two to succeeding formations are essentially identical.

While no correlation across so great an interval as the Atlantic can command the utmost confidence until the cause of glaciation shall have been demonstrated, and shall have been shown

to be such as to operate in like ways on both continents at the same time, it is nevertheless interesting to make such correlation as the formations permit, and it may be profitable if held in due restraint. The parallelism between the Kansan and the Saxonian formations is fairly close and certainly suggestive.

The Aftonian (*=Helvetian?*).—Subsequent to the formation of the Kansan sheet of till, and accompanying assorted deposits, there was a very notable retreat of the ice. Mr. Upham, whose inclination to unify and limit the extent of the glacial period makes his judgment especially valuable on this point, expresses the opinion that the retreat reached an extent of 500 miles.[1] This judgment is based upon the occurrence of interglacial peaty deposits in the basin of Lake Agassiz. If we recognize a subsequent retreat of considerable moment between the Iowan and Wisconsin stages, it will not perhaps be clear that these deposits do not belong to the later interval; but even under this interpretation, the retreat must still probably have exceeded 300 miles. During this stage of retreat there were accumulations of muck and peat reaching a reported depth of twenty-five feet. One of the best exposures of this horizon is found between Afton and Thayer, Iowa, and from the former a euphonious name may be taken. Owing to the scarcity of gravel in the drift territory of southern Iowa, the Chicago, Burlington & Quincy Railway has made very extensive excavations upon three gravel deposits lying between an upper sheet of till reaching a thickness of forty to sixty feet and a lower till of less depth. The gravels appear to be kame-like accumulations, at least they are great lenses lying upon the surface of the lower till. This lower till is believed to belong to the Kansan stage and the upper to the Iowan. On the surface of the gravels there accumulated, at points, a deep mucky soil, in which occur considerable quantities of vegetal débris. This is believed to occupy the same horizon as the numerous peaty deposits described by McGee in eastern Iowa.[2] To this horizon also is referred the peat beds lying between the two outer till

[1] WARREN UPHAM: Am. Naturalist, Vol. XXIX., 1895, March, p. 237.

[2] Eleventh Annual Report U. S. Geological Survey, p. 487.

sheets of southeastern Minnesota, described many years ago by Professor N. H. Winchell.[1] The fauna and flora of this horizon have not yet been adequately worked out, but their general indications are not unlike those of the Helvetian stage of Europe, as defined by Dr. Geikie. A tentative correlation of the two may therefore be made.

The Iowan formation (=*Polandian?*).—This embraces an extensive sheet of till lying upon the preceding interglacial deposits and having its best known expression in eastern Iowa, where it has been most carefully worked out by McGee. It is known to have considerable extension in adjoining states, but its full distribution is not yet ascertained. It is intimately associated with the most important of the loess deposits. In some places it appears to graduate at its edge into loess which spreads far away from its border. In other places, it seems to pass up by graduation into a loess mantle. To avoid misunderstanding it should be remarked that minor deposits of loess are associated with other sheets of drift, and loess is not necessarily characteristic of any horizon. The close association of the greatest loess deposits with the Iowan formation is, however, significant of the conditions under which it was formed.

The Iowan formation stands in a relation to the American series similar to that of the Polandian to the European series. It has, furthermore, similar characteristics in constitution and surface expression. I believe I am correct in saying that the chief loess deposits of south Germany and Russia are associated with the Polandian formation in much the same way that the chief loess of the Mississippi basin is associated with the Iowan deposits. In a tentative correlation, therefore, the Iowan and the Polandian formations may plausibly be regarded as equivalents.

The Toronto formation (=*Neudeckian?*).—Through the recent investigations of Coleman[2] and others, and the earlier studies of

[1] N. H. WINCHELL: Proc. A. A. A. S., Vol. XXIV., 1875, Pt. II., pp. 43–56; Geol. Minn., Final Rep., Vol. I., 1884, pp. 313, 363, 390.

[2] A. P. COLEMAN: Interglacial Fossils from the Don Valley, Toronto. Amer. Geologist., Vol. XIII., February, 1894, pp. 85–95.

Hinde,[1] it has been shown that there is a very important series of fossiliferous beds in the vicinity of Toronto, interstratified between till sheets. There are two series of fine laminated shales and sandstones separated by a sheet of till, with till overlying the whole, and presumably also underlying the whole. In the lower stratified series, whose thickness Dr. Hinde gives as 140 feet, the silts and sands contain organic remains from bottom to top. These embrace a considerable variety of forms, the most notable of which are the remains of lepidopterous insects, all of which have been pronounced by Scudder to be extinct. These beds are exposed on the face of Scarborough Heights a few miles east of Toronto. Along the river Don, in the immediate suburbs, Professor Coleman has found a remarkable group of molluscan forms and of plants in laminated clays and sands that were at first supposed to be equivalent to the fossiliferous series of Scarborough Heights. But Professor Coleman informs me that he has reasons for doubting the correctness of this correlation, and thinks it not impossible that the beds on the Don may correspond to the upper clays and shales in the Scarborough section. If this should prove true (and this statement should not be construed as in any way committing Professor Coleman) we shall have here two fossiliferous series requiring correlation. The series on the Don contain molluscan forms, chiefly unios and their relatives, which belong to the Mississippian, rather than to the Atlantic, drainage area. They also contain plants that indicate a more genial environment than that of Toronto at present. From the fact that the molluscan forms appear to have passed over the divide between the Mississippi and the St. Lawrence basin after the retreat of the earlier ice, and to have been subsequently forced out of the basin, presumably by the return of the ice, which formed the overlying till sheet, it has seemed possible, if not probable, that the beds upon the Don belong stratigraphically between the Iowan and the overlying Wisconsin beds. It will be observed that the grounds

[1] George Jennings Hinde: The Glacial and Interglacial Strata of Scarborough Heights and other localities near Toronto, Ontario. Can. Jour., April, 1877.

for this correlation are not very strong, and investigation may show them to be erroneous. It is not likely, however, that the beds upon the Don can be referred to any earlier period. They may be later. Should the beetle-bearing beds at the base of Scarborough Heights prove to be distinct from the molluscan beds on the Don, the former may perhaps be found equivalent to the Aftonian beds previously described. Whether the beds on the Don belong to the horizon suggested or not, it is certain that vegetal beds were formed in the interval of the retreat between the formation of the Iowa till and the formation of the Wisconsin till, and some of these less well developed and less known deposits must be looked to as a type of this interglacial horizon, if the Toronto beds prove unavailable.

If the fossiliferous clays and shales on the Don belong to the interval between the Iowan and Wisconsin formations, they may be tentatively correlated with the Neudeckian of Geikie.

The Wisconsin formation (= *Mecklenburgian* ?).—Overlying the interglacial beds above the Iowan deposit, comes the most massive of the American till sheets, occupying the larger part of the territory of the northern states and very large sections of Canada. This is distinguished by a series of gigantic terminal moraines, stretching across the country in an undulatory fashion already well known to students of the subject. There are at least two divisions of the moraine-bordered tills, with a somewhat notable interval between the two, during which there was considerable rearrangement of the frontage of the ice. As a result of this, some of the later moraines run at large angles across the earlier ones, riding over them in a quite disregardful fashion.

In like manner there occurs upon the northern plains of Germany a series of similar gigantic moraines associated with thick till sheets. There are also pronounced but less massive moraines in southern Scandinavia and Finland. The two series are interpreted as representing a single stage by Dr. Geikie, but to one at a distance, and without personal familiarity with deposits, the suggestion that they represent two episodes having some such relation to each other as the two subdivisions of the

Wisconsin formation arises, and may be mentioned for what it is worth, which is probably very little. The chief characteristics of the European morainic series are strikingly similar to those of the American, as long since pointed out by Salisbury.[1] In addition, therefore, to the similarity of position in the European series which the Mecklenburgian series bears to that of the Wisconsin formation in the American series, there is a striking correspondence in the individual characteristics of the two. Beyond any question these individual characteristics were due to some common condition or combination of agencies. If the fundamental cause of glaciation was such as to involve intercontinental contemporaneity of action, the correlation of the two has much in its support.

Later deposits.— Investigation in America has gone far enough to make it certain that subsequent to the deposit of the Wisconsin formation, there was a somewhat complex series of events before the Ice Age entirely passed away. It has not, however, gone far enough to make it clear precisely what the stages were, and it is perhaps premature to attempt to designate the specific formations which resulted. A series of beach lines along the lower lakes has been specifically connected with moraines by Leverett and others, indicating a coincidence of lake action and ice action. On the north side of the lakes it is known that there are several very considerable terminal moraines indicating at least halts, and possibly advances, of the ice subsequent to its retreat from the territory of the United States. It is every way probable that some of these will deserve a special taxonomic place when sufficiently traced out. If the fossiliferous beds of Toronto are later than the Wisconsin formation, they and the overlying till certainly merit special recognition. There is therefore abundant room for the belief that stages of action equivalent to the Turbarian and Forestian of Dr. Geikie may be found.

In carrying out this parallel, it has not been the design of the

[1] R. D. Salisbury: Terminal Moraines in Northern Germany. Am. Jour. Sci., 3d series, Vol. 35, 1888, pp. 401–407.

writer to indicate a judgment respecting the specific value of the several formations, either in terms of taxonomy or chronology. It has been thought, however, that it would promote a mutual understanding of the formations of Europe and America if some approximate equivalence could be shown between the two unquestionably complex series. It will perhaps promote the differentiation of the two series to institute mutual comparisons, and it may facilitate a final judgment of the value of these subdivisions if we are able to compare, formation by formation, the distant series with that which falls within our own field of investigation.

T. C. CHAMBERLIN.

THE VARIATIONS OF GLACIERS.

THE great interest which the physical study of living glaciers has to the geologist is the light it may throw on causes producing, and conditions prevailing during, the Ice Age. One of the habits of living glaciers bearing most directly on the Ice Age is the variation continually occurring in their length, thickness and velocity of motion. All students of glaciers have collected reports and made observations themselves on the advance and retreat of the ends of particular glaciers, but it is only within about twenty years that anything like systematic work has been done in getting together records which enable us, in some cases, to exhibit roughly the variations in the extent of certain glaciers for three hundred years, during which period there has been quite a number of advances and retreats; observations since the fifties give us a fair record of the movements of some Swiss glaciers.

What are the causes of these variations? The answer of course is that they are meteorological, for it is quite evident that the extent of a given glacier depends on the snow-fall and the rate of melting; the ice continues to flow down its valley until it is all melted away. Anything that increases its velocity will make it flow further, and anything that increases its rate of melting will cut it off shorter. But which of these factors has been most important in determining the changes which have actually occurred? M. Forel has argued ably[1] that it is the change in velocity. He has shown that glaciers have varied very much in extent when there has been no great change in the rate of melting; that this has been due to a change in the velocity, which in its turn depended on a change in snow-fall. If this proves to be universally the case we have the following interesting application to make to the ice of the Ice Age: If the

[1] Bibliotheque Universelle de Geneve, VI., pp. 5–49, 448–460.

floods which occurred at the time when the ice-sheet was at its maximum (*i. e.*, when the melting area was greatest), were stronger than those which occurred later, we may infer that the retreat of the ice was due rather to a diminution of the snow-fall than to an increased rate of melting, brought about by a warmer climate; whereas, if the stronger floods occurred after the ice had retreated some distance (*i. e.*, when its area was smaller), we may infer the opposite.

How soon does a glacier respond to climatic influences? This is a question which cannot be answered directly; usually we find some glaciers advancing and others retreating at the same time; for instance, a little before the middle of this century the Alpine glaciers were apparently all advancing; one after another ceased to advance and began to shorten, the number joining the retreating forces being greatest between 1850 and 1860; but it was not until 1870 that all were losing ground; for five years thereafter no glacier in the Alps was known to be advancing; in 1875, the glacier des Bossons, on Mt. Blanc, led the beginning of a new advance; since then others have joined it, until now some fifty or sixty are advancing. Peculiarities show themselves in the changes; glaciers in the same mountain group, and even glaciers so closely related as the Findelen and Gorner, near Zermatt, whose *névé* regions adjoin, are sometimes moving in opposite phases at the same time. In general there seems to be a readier response on the part of the smaller glaciers; and the steeper ones also seem to start earlier than the others; but as far as I know variations have not been analyzed according to the size, slope, height, exposure of the glaciers, etc.; in fact, it would be extremely difficult to analyze them properly without the guidance of a mathematical theory, which would enable us, when given the dimensions of a glacier, to calculate the velocity in its different parts. Material, however, is being collected which will form a basis for such a theory, in the general records of the movements of glaciers, and more particularly in the accurate observations which are annually made on the Rhone glacier under the auspices of the Swiss Alpine Club, and on some other glaciers.

M. Forel has collected and discussed the records of variations of glaciers in a series of most interesting reports to the Swiss Alpine Club.[1] He finds that glaciers go through periodic changes of from thirty-five to fifty years' duration.[2] Beginning with a glacier at its minimum the changes occur in the following order: First comes an increased velocity due to increased snow-fall, and the glacier advances rather rapidly; later the velocity diminishes, the glacier reaches its maximum, and then begins to retreat. During this whole period the rate of melting may not have changed at all markedly. The advance is rapid, taking about a third as long as the retreat, which is merely a time of melting, during a diminished flow, until a new advance, produced by increased snow-fall, begins again. The average for quite a number of glaciers observed during this century gives a complete period of thirty-eight years or more. But the subject is much complicated by the fact that different glaciers begin and end their advance at widely different times; so different indeed, that we can frequently in a given year find different glaciers representing all phases of advance and retreat. This makes the task of comparing variations of climate with variations of glaciers very difficult, for one does not know what to consider the time of maximum or minimum advance.

Some progress has however been made; Professor Brückner[3] starting with the fact that glaciers have periodic changes, made an exhaustive study of the variations in the heights of lakes, of interior seas; of the inundations of rivers, and the duration of their winter freezing; of agricultural matters, such as the times of vintage, etc., and found a similar period in them all. He then took up meteorological observations proper and found the same thing. His researches reach back to 1700. He was able

[1] Jahrbuch des Schw. Alp. Club, from 1881 to date. I am indebted to Professor Forel and Professor Richter (cited below) for almost all the material of this paper.

[2] American glaciers are in general retreating, but observations have not been frequent enough to show a periodicity in their movements.

[3] Klima-Schwankungen seit 1700. Geog. Abhand. von Dr. Penck, 1890, IV. (cited by Professor Forel).

to state that since then, and presumably before, the climate has oscillated about its mean in a period of thirty-five years. Professor Richter[1] by a careful study of the historical records of Alpine glaciers, has confirmed this, and has carried it back another hundred years. He has shown that the average period of the variations of glaciers for the last three hundred years has been the same as Brückner's period. He has also shown that during the present century the larger number of glaciers have begun to advance very soon after the beginning of a cold period of increased precipitation, though some of the larger ones have started only twenty or even thirty years later. We wish now to know the relation connecting the time of increased precipitation with the time of advance of glaciers, as a function of their size, slope, etc.

Two theories have been advanced to explain the *modus operandi* of glacial variations. Professor Richter[2] thinks that there must first be an accumulation of snow in the *névé* regions, which at last produces a great enough pressure to overcome the resistance, due to the friction against its bed, of the glacier's tongue; which is then pushed forward with a greater velocity, resulting in an advance of the glacier; this continues until the drain on the *névé* regions, on account of more rapid flow, exhausts the accumulation of snow; after this the motion almost entirely ceases, and the glacier melts back until another advance begins. Professor Forel[3] calls this the "theory of intermittent flow," and points out that according to it variations in the size of glaciers would occur entirely independently of meteorological changes. He had, in 1881, offered a "theory of continuous flow."[4] According to this theory the glacier responds immediately to increased snow-fall, but only in its upper part is there an immediate increase in velocity; this pressing forward of the ice

[1] Geschichte der Schwankungen der Alpengletscher. Zeits. des deut. u. Oest. A–V., 1891. This is a most important paper.

[2] Der Obersulzbach Gletscher, 1880–82. Zeits. des deut. u. Oest. A–V., 1883.

[3] Jahrbuch des Schw. Alp. Club, 1887–88.

[4] Bibliot. Univ. de Geneve, 1881.

from above results in a progressive thickening of the glacier from above downward. Though the increase in the thickness and velocity may have begun in the upper regions, the end may still be melting back; when, however, this increase in thickness reaches the lower end the advance will begin, for there will be a greater quantity of ice and it will have a greater velocity; it will therefore have to travel further before being melted away. After a while, the snow-fall becoming less, the glacier will gradually decrease in thickness, and consequently in velocity, until the rate of melting exceeds the rate of flow, when the retreat will begin. Comparatively small changes in snow-fall result in marked movements of the glacier's end; for not only is the thickness of the ice at the end changed, but the velocity is also, and these

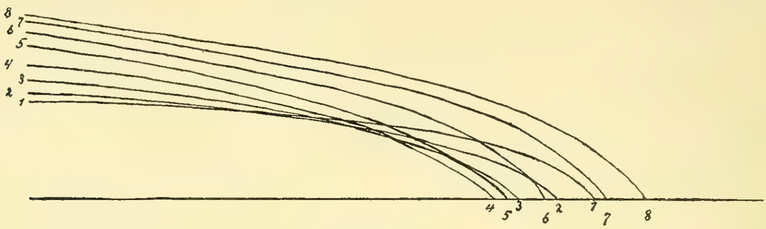


FIG. 1.

two factors so interact that an increase of one produces an increase of the other, and the reverse. This can be made clearer by a diagram.

In Fig. 1, let line 1 represent the surface of the glacier when the *névé* fields are lowest; suppose now the snow-fall increases; the *névé* fields get thicker, but the end is not affected, and it continues to melt back; the lines 2, 3, etc., represent the surface at successively later times. After a while the thickening and consequent increase in velocity of the lower end causes it to advance.

Similarly the continued advance after the snow-fall has begun to diminish, and the later retreat, may be illustrated by Fig. 2.

The question of glacial erosion is a very important one; the

geological evidence has not led geologists to a uniform opinion. We know little about the velocity below the surface of the glaciers; can we find out how rapidly glaciers are sliding over their beds? This is certainly very difficult to do; in fact the only place where observations can be made is near the end of the ice or at the sides where the movement is slow. During the last thirty or forty years, a period of retreat, the movement has been slower than it will be during the advance now beginning; observations made during the retreat would certainly lead to an underrating of the effect of a glacier on its bed; but during the more rapid movement of the advance we shall form a better estimate of it. A mathematical theory might enable us to infer

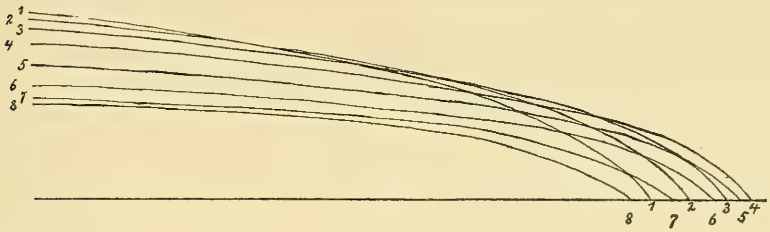


FIG. 2.

the velocity at the bottom from that at the surface; this would certainly be an immense gain in our knowledge of glaciers and ice-sheets. It is for this reason that experiments on the physical properties of ice, and observations on the rate of flow, rate of melting, and comparisons of the variations of glaciers with climatic variations, etc., are of so much importance to the glacial geologist.

The study and observations of the variations of glaciers is being pushed with great zeal by the various Alpine clubs, and the results published in their journals, where they are apt to escape the notice of American geologists. Last summer the International Congress of Geologists at Zurich appointed a committee to encourage, and to collect, observations on glaciers all over the world, with the special object in view of discovering a relation between the variations of glaciers and of meteorological

phenomena.[1] It is with the hope of enlisting the coöperation of American geologists, and others who may be willing to help, that this paper has been written.

There are a number of small glaciers in the Sierra Nevada mountains, larger ones on the old volcanoes of the Cascade Range and in British Columbia, and immense ones in Alaska. Opportunities for making observations on many of these glaciers will frequently arise, even to travelers, who, if willing, can contribute to the problem of the variations of glaciers.

There are two glaciers in North America that are so frequently visited that we should secure a very complete set of records of them; they are the Illecellewaet in the Selkirk Mountains and the Muir in Alaska. I add a short list of the observations that should be made, and the methods; many are simple, and easily made by travelers.

OBSERVATION OF GLACIERS.[2]

It is desired to obtain a general description of little known glaciers; to determine at the time a glacier is visited whether it is advancing, retreating or stationary; to determine the year of maximum advance or retreat; to collect observations of travelers which may throw light on the extension of a glacier at an earlier

[1] This committee representing various countries is as follows:

Austria: Professor Ed. Richter, Graz.
Germany: Professor S. Finsterwalder, Munich.
United States of America: Dr. Harry Fielding Reid, Baltimore.
Denmark: Dr. R. I. V. Steenstrup, Copenhagen.
France: Prince Roland Bonaparte, Paris.
Great Britain and Colonies: Captain Marshall Hall, Dorset.
Norway: Dr. A. Ojen, Christiania.
Russia: Professor Ivan Mouchketow, St. Petersburg.
Sweden: Dr. F. U. Svenonius, Stockholm.
Switzerland: Professor F. A. Forel, Morges; Dr. Leon Du Pasquier, Neuchatel.
A representative of Italy has not yet been appointed.

[2] In making out this list of observations and methods, I have had the advantage of consulting the papers of PROFESSOR FOREL in the Jahrb. des Schw. A. C., 1882–83, 1883–84, 1890–91; the instructions of PROFESSORS KILIAN and COLLET in the Annuaire de la Soc. des Tour. du Dauphine, for 1891, and the memorandum of the Alpine Club, cited below.

date; to record the extent and thickness of the glacier as often as possible; to determine the velocity of flow of the ice; to determine the rate of melting of the ice.

General description.—Name. Latitude, longitude and altitude of end. General direction of flow.

General description of glacier (Is it long or broad? Is it in a narrow valley, or on a plateau? Is it simple or made up of several tributaries? Is it smooth or much crevassed? Are there any ice-falls? Are there moraines on the ice? Altitude of *névé* line; size of *névé* fields and of tongue; a sketch map of an unsurveyed glacier is useful).

Slope of glacier.—(1) Slope of surface in different parts of the glacier; (2) estimate of slope of glacier's bed, where possible.

Old moraines.—Describe their forms, condition and distance from the glacier, if terminal, and their height above the ice, if lateral.

Lakes.—Are they true rock-basins or dammed lakes? For rock-basins determine the form of the bed by soundings, if possible.

Recent changes.—(*a*) Question anyone who may be able to give information whether the glacier has recently been larger or smaller than at present, and when it began to advance or retreat.

(*b*) Obtain photographs of the glaciers with date when taken. "The earlier recent movements of glaciers may be noted by the following signs:

"When the ice is advancing, the glaciers generally have a more convex outline, the ice-falls are more broken into towers and spires, and piles of fresh rubbish are found shot over the grass of the lower moraines. Moraines which have been comparatively recently deposited by advancing ice are disturbed, show cracks, and are obviously being pushed forward or aside by the glacier.

"When the ice is in retreat, the marks of its further recent extension are seen fringing the glacier both at the end and sides in their lower portions; the glacier fails to fill its former bed, and bare stony tracts, often interspersed with pools, or lake-

lets, lie between the end of the glacier and the mounds of recent terminal moraines."[1]

Future changes.—For this purpose all records of the extent and thickness of the ice at date of observation are useful.

The position of the end may be recorded as follows:

(*a*) Measure distance of one or more points of the glacier's end from cairns or prominent rocks, which should be marked by paint or chisel. Or, take magnetic bearings of a tangent to the end of the glacier from a station on the valley's side; this tangent should be about at right angles to the direction of the valley.

(*b*) Photographically.—(1) All photographs of the end of the glacier are useful; particularly if the magnetic bearings of the camera, and the approximate distance from the glacier are given. (2) Select two stations, one on each side of the valley, commanding a view of the glacier's end. Photograph the end from these two stations; two photographs from each station may be required to show all the end. Mark the stations, describe them carefully and leave an account at the ranch or hotel from which the glacier is usually visited so that they can easily be found by later observers, who should take photographs from these points in preference to all others. This will be the beginning of a systematic record of the glacier. From these photographs it will be possible to make a map of the glacier's end if we know: the distance between the stations; the angle at each station between the other and some point in each photograph and the focal length of the lens, or the angles at each station between the other and two points in each photograph, not less than half the length of the plate apart; the bearings of these two points will enable us to determine both the direction in which the camera was pointed and the focal length of the lens.

An observer, provided with a small theodolite (or even a prismatic compass) should measure from each of the stations the angle between the other and all prominent peaks or other points likely to appear in the photographs, and should determine the distance between the stations. This need only be

[1] Memorandum on Glacier Observations, issued by the Alpine Club, June, 1893.

done once, after which all earlier and future photographs taken from these stations can be used to mark accurately on the map the glacier's end at the date they were taken. If vertical angles also are measured, and the difference in altitude of the stations determined, contour lines can be added to the map. This method yields the greatest amount of information for the least amount of trouble.

The stations should be selected so as to be as easily accessible and recognizable as possible; the distance between the glacier's end and the line joining them should be between one-seventh and twice their distance apart; nearer the former if the glacier is retreating, nearer the latter if it is advancing.

In taking the photograph have the camera as level as possible, with the plate vertical; do not use the swing back, and do not alter the focus in taking two or more pictures from the same station. Hand cameras should rest on some support; a rock answers well. The longer the focal length of the lens, the better; negatives or positives on glass yield more accurate results than prints, as the paper may become distorted in the manipulation.

Variations of thickness.—(*a*) Select a station on the side of the glacier's valley. Mark it. Select a direction about at right angles to the glacier and record it by compass bearing or by the angle it makes with some easily recognizable point. Determine by aneroid barometer the difference in level between the station and the following points on this line: (1) the sides of the glacier; (2) the highest point of the glacier; (3) any other points feasible. If possible record the difference in level between station and the end of the glacier or some base station.

(*b*) Observe by aneroid or measure the vertical distance between some easily recognizable point in the *névé* region, such as a projecting rock, and the glacier's surface at its side. If possible note difference of level between this station and some base station.

Velocity of flow.—Persons provided with instruments can readily determine the velocity of flow by sighting on a line of stakes or on some prominent bowlders at intervals of a few days.

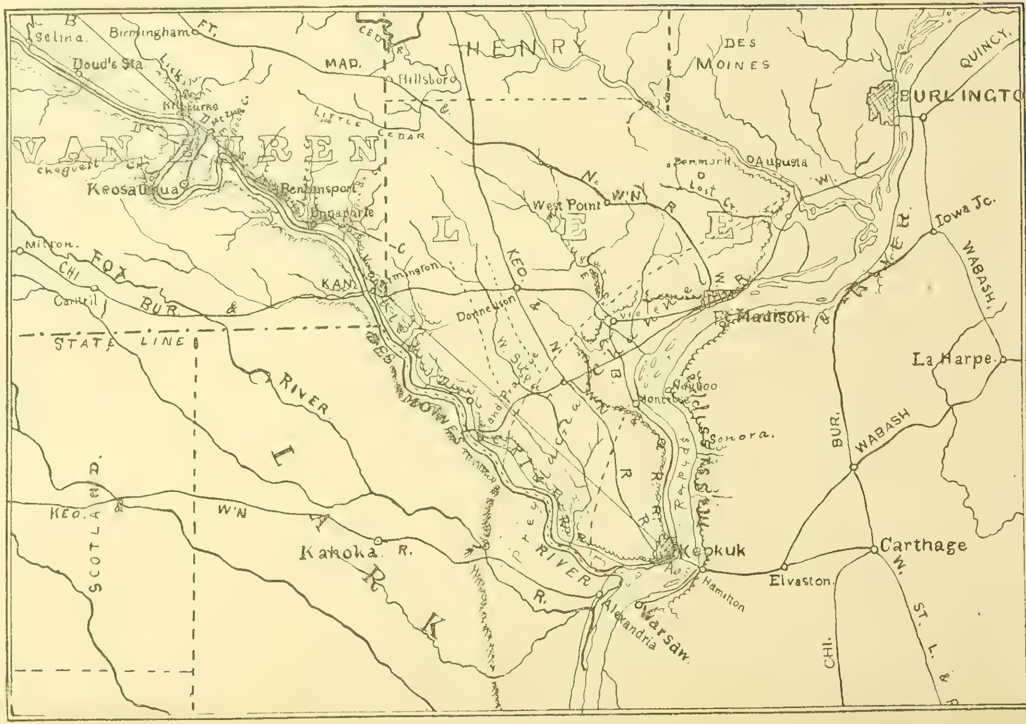
Another method, which yields average velocities, is to determine the position on the ice of some prominent bowlder which is marked, so that it can be recognized after one or more years, and the distance it has moved measured. A very good way is to lay out a line of sheet-iron plates, say, three inches square, on which is painted the date when, and the position where, they are placed. These will sink slightly into the ice, will not be blown away by the wind, and will not roll or slip, as bowlders may. They can be recovered and the distance moved over determined by a future observer. Stones are used in this way for the observations on the Rhone glacier.

Rate of melting.—At the lower end of glaciers, when the ice is somewhat disintegrated and will not in general hold water, the melting can be measured by boring an auger hole in the ice and putting a stick in it; the apparent rise of the stick out of the ice will be the measure of the melting. If the ice is compact enough to hold water, this method may yield inaccurate results; it is better then to bore two holes starting from the same point on the surface of the ice and making an angle with each other of 45° to 60°, put a stick in each hole and where they cross bind them firmly together with wire. The ice will melt around the sticks, but each will prevent the other from sinking into its deepened hole. The wire may be used as an index, and its increasing height above the ice will measure the melting.

All photographs and observations sent me[1] will be carefully filed away and preserved as the record of the history of the glacier in question; they will be considered as the property of the Geological Society of America. A poor photograph is much better than none. Prints should be mounted on linen or unmounted. On each should be marked the glacier depicted the date, the station from which the picture was taken, the direction in which the camera was pointed and whether or not the lens used was rectilinear (or give the name of the lens), If its focal length is known, it should also be given.

Harry Fielding Reid.

[1] Address Johns Hopkins University, Baltimore, Md.



Sketch Map of Southeastern Iowa.

STRATIGRAPHY OF THE SAINT LOUIS AND WARSAW FORMATIONS IN SOUTHEASTERN IOWA.[1]

CONTENTS.

INTRODUCTION.

THE stratigraphic relations of the Saint Louis and Warsaw groups in southeastern Iowa have not hitherto been satisfactorily established. The beds succeeding the geodiferous shales of the Keokuk group, first erected into an independent group—the Warsaw—by Hall in 1858, have been included in the Saint Louis group by some writers, while others have referred them to the Keokuk. From a careful survey of the literature it is evident that much of the confusion attending our knowledge of these rocks has arisen from discordant conclusions derived from investigations within the area covered by this paper. As these differences appear to have arisen chiefly from the variable character of the Saint Louis limestone, special attention was given to

[1] Published with the permission of the state geologist of Iowa.

the study of this formation by the author, in the field work of 1893, under the auspices of the Iowa Geological Survey.

EARLIER DESCRIPTIONS.

Owen, 1852.—The first account we have of the geology of this region is that of Owen in 1852.[1] While detailed work was not attempted, his descriptions give evidence of close and accurate observation. He divided the Lower Carboniferous into an upper and a lower series, and named the various subdivisions from lithological or faunal characteristics. No attempt was made to correlate with rocks in other regions of the United States, but in accordance with the prevailing usage of that time he essayed to establish the equivalency of the divisions of the upper series with the members of the Carboniferous section of Yorkshire.

OWEN'S SECTION OF THE LOWER CARBONIFEROUS.

Upper Series.

f. Upper concretionary limestone.
e. Gritstones.
d. Lower concretionary limestone.
c. Gritstones.
b. Magnesian limestones and shales.
a. Geodiferous beds.

Lower Series.

f. Archimedes limestones.
e. Shell beds.
d. Keokuk cherty limestones.
c. Encrinital group of Hannibal.
b. Encrinital group of Burlington.
a. Argillo-calcareous group of Evans Falls.

The gritstones (*e*) of the upper series are said to be marked by the presence of lepidodendron, calamites, and other Carboniferous plants. The sandstones here referred to are, doubtless, the Keosauqua sandstones. Careful search, however, has

[1] OWEN, D.D., Geological Survey, Wis., Ia. and Minn. U. S. Govt., 1852, p. 92.

failed to reveal any plant remains in this deposit, and it is evident that Dr. Owen confounded this sandstone with the basal sandstone of the Coal Measures which is often found occupying depressions eroded in the limestones. Moreover, the study of the region shows that while the succession represented by *c*, *d*, *e*, *f* of the upper series is in a general way correct for particular localities, the members are rather local in their development, and grade more or less into each other. They cannot, therefore, be assigned a position equivalent to the remaining and more general members of the section. The brecciated limestone so often referred to by later writers is included under the lower concretionary limestone (*d*), though very little is said of it.

Hall, 1858.—In the report issued in 1858,[1] the formations are treated in greater detail and a fuller classification is adopted. The geodiferous beds are included in the Keokuk group, while Owen's divisions, *b* and *c* of the upper series, are erected into the Warsaw group, so named from the town on the east bank of the Mississippi, opposite the mouth of the Des Moines River. The remaining members of the series are referred to the Saint Louis group as established by Shumard of the Missouri survey.

Worthen.—In the report made by Worthen on the geology of the Des Moines Valley, the Keosauqua sandstone is evidently identified with the basal sandstone of the Coal Measures. In the report on the geology of Lee county referring to the brecciated limestone he says: "The changes in the lithological characters of this bed, which forms one of its most striking peculiarities, probably led Dr. Owen into the erroneous supposition that there were two distinct beds of concretionary limestone which he has represented in his general section with a bed of sandstone between." Since Dr. Owen's section can be verified locally, as will appear in the sequel, the error is clearly on the other side. Moreover, the magnesian limestones at the base of the Warsaw[2] group are identified with those occurring on the Des Moines containing *Lithostrotion canadense*, and hence unquestionably belonging to the Saint Louis limestone, a conclusion directly contrary

[1] Geology of Iowa.

[2] Vol. II., Part. I., p. 193.

to the recognition of the Warsaw as a distinct group. In 1866, Geology of Illinois, Vol. I., these formations are held to be related to the Saint Louis and are all included under that group.

White, 1870.—In this report[1] the description of these rocks is still more contradictory. The beds included under the Warsaw group were all referred to the Saint Louis apparently under the erroneous assumption, previously made by Worthen, that the magnesian limestones at the base of the Warsaw are the equivalents of the Lithostrotion beds along the Des Moines. In referring to the character of the Warsaw beds as seen at the typical locality this author says: "The bluish argillaceous shales which so prominently characterize the exposures of this formation at Warsaw are scarcely recognizable in Iowa."[2] This statement, however, is at variance with Hall's observations, as also our own, as shown by sections given in this paper. Moreover, the sandstone or arenaceous limestone representing the upper member of the original Warsaw is correlated with the Keosauqua sandstone, whereas the former is underneath the brecciated limestone, while the latter is above.

In 1890 the writer[3] called attention to the brecciated character for the purpose of suggesting a possible explanation of its origin.

Keyes, 1893.—In Vol. I. of the Iowa Geological Survey[4] the Warsaw beds are recognized as being closely allied to the Keokuk group faunally, stratigraphically and to a less marked degree lithologically. It is not regarded as of sufficient importance to warrant a separation and is, therefore, included in the Keokuk group, while the discontinuance of the name Warsaw as a title equal in rank to Saint Louis, etc., as advocated by White is sustained. As the removal of the Warsaw beds carried with them their supposed equivalents, the magnesian limestones along the Des Moines, the brecciated limestone is described as constituting the basal member of the group in Iowa.

[1] Geology of Iowa, Vol. I.

[2] Geology of Iowa, Vol. I., p. 218.

[3] American Naturalist, April, 1891.

[4] KEYES, C. R.: Geology of Iowa, 1892, Vol. I. p. 70.

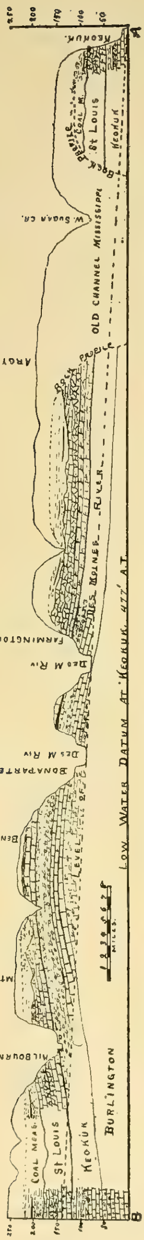


FIG. 1.—Section line A-B from Keokuk to northwestern corner of Van Buren county. (See map.)

GENERAL DESCRIPTION OF THE REGION.

The area included in this investigation comprises the two counties of Lee and Van Buren. The former lies on the north side of the Des Moines River at its confluence with the Mississippi, while the latter joins Lee on the west and is traversed by the Des Moines River diagonally from northwest to southeast. This river and most of its tributaries, as well as those of the Mississippi, have penetrated the drift and cut deep channels into the underlying rock, thus offering favorable opportunities for the study of these formations.

The general relief of the region is that of a broad, flat plain gently sloping to the southeast, and intersected by a parallel system of drainage dating from the withdrawal of the ice-sheet. Considerable areas have, as yet, been but partially invaded by the backward erosion of the streams, and the divides are still characterized by flat tops representing the original plain out of which they have been carved.

STRATIGRAPHY OF THE REGION.

Structure.—In this region, the rock floor upon which the drift rests is made up chiefly of the Lower Coal Measure deposits and the Saint Louis limestone. By the erosion of the streams, however, lower formations are frequently exposed so that the area has furnished typical sections of a considerable part of the Lower Carboniferous series. Extensive preglacial erosion has greatly reduced the surface area of the Saint Louis

and Coal Measure rocks. They now occur in three areas separated by extensive drift-filled preglacial channels. In Van Buren county no decisive evidence of similar channels has been obtained, but from the great thickness of drift shown by certain well records, and from other indications, there is reason to suspect that Fox River occupies approximately the position of an older stream.

Description of sections.— In the Illinois Geological Report, Vol. I., Worthen has included the Warsaw beds in the Saint Louis group and gives the following section of these rocks at Warsaw:

I. SECTION AT WARSAW.

1. Concretionary brecciated limestone,	30′
2. Arenaceous limestone,	10′
3. Blue argillaceous shales and limestones,	30′
4. Magnesian limestone,	12′
	82′

In this section, Nos. 2, 3 and 4 constitute the Warsaw as established by Hall. At Keokuk the beds between the Geode Shales and the Coal Measures are as follows:

II. SECTION AT KEOKUK.

1. Brecciated limestone; the fragments composed of gray compact limestone, sometimes firmly cemented by similar calcareous material, in other cases with the interstices filled with green clay,	10′–30′
2. Calcareous sandstone; blue, weathers brown; in some cases quartz grains numerous and coarse,	8′
3. Blue argillaceous shale with thin variable beds of limestone, the latter subcrystalline and fossiliferous,	20′
4. Magnesian limestone, brownish gray; in some places coarse subcrystalline, in others fine and of a bluish color; weathers to a yellowish brown,	4′
	62′

The calcareous sandstone (No. 2) corresponds to No. 2 of the Warsaw section and is quarried to some extent both above and below the city. The limestones of Nos. 3 and 4 are marked by the presence of numerous fossils among which the remains of Bryozoa, notably Archimedes and Fenestella, are especially abundant. The beds 2, 3 and 4, representing the original Warsaw, have a marked correspondence to the equivalent deposits at Warsaw though considerably reduced in thickness.

Excellent exposures of the Saint Louis limestones occur at various localities on East Sugar Creek:

III. EAST SUGAR CREEK SECTION.

1.	Compact light gray limestone; breaks with conchoidal fracture, -	3′
2.	Light brown friable sandstone, - - - - -	10′
3.	Compact fine-grained limestone, - - - -	1′
4.	Friable calcareous sand, - - - - - -	10′
5.	Brecciated limestone; fragments mostly of light-colored compact limestone well cemented by similar calcareous material, - -	15′
6.	Brown magnesian limestone, slightly arenaceous in places; somewhat thick and irregularly bedded; contains lenticular masses of brecciated limestone similar to No. 5, - - - -	10′
7.	Blue arenaceous shale; includes fragments of chert and siliceous limestone, - - - - - - - -	6′
		55′

This section occurs on the branch of East Sugar Creek flowing through West Point township. The brecciated limestone is rather coarsely stratified, and appears smooth and waterworn in places. At one point a looser aggregate of the same character occupies what appears to be a channel eroded in the more compact breccia. The lenticular masses occurring near the base of the magnesian beds do not differ essentially from the main mass of the brecciated rock. Near the top of the magnesian beds, however, the lenticular masses are composed, in part, of fragments resembling the brown magnesian limestone itself. At Graner's quarry in the N. W. ¼ Sec. 30, T. 68 N., R. 5 W., the beds above the brecciated limestone are represented by sixteen feet of coarse granular limestone, or calcareous sand rock, cross bedded and prominently ripple marked. Beneath the granular limestones there are about eight or ten feet of brecciated limestone followed downward by the same thickness of brown magnesian limestone. A shaft and drill hole penetrated thirty feet of shale below this bed, the upper ten of which was destitute of geodes and apparently represents the Warsaw shales.

One-half mile southwest of the quarry the granular limestones are replaced by fine compact gray limestone containing more or less nodular chert.

At a small quarry one and one-half miles south of Donnellson,

the granular limestones are seen underlain by the brecciated limestone and this by brown magnesian limestone in which *Lithostrotion canadense* was found. This bed is arenaceous in appearance and is locally termed a sandstone.

On the Des Moines River, about a mile below Belfast, the calcareous sandstones represented by No. 2 of the Keokuk and Warsaw sections are twenty to twenty-five feet thick and change locally to blue arenaceous shale. About a half mile east of this locality, a quarry shows the following arrangement:

IV. SECTION AT DEAMUDE'S QUARRY.

1. Clay, yellow above, red below, - - - - - -	6′
2. Brecciated limestone with pockets of green clay, - -	20′
3. Hard blue limestone varying to blue arenaceous shale or shaley sandstone, - - - - - - - -	3′
4. Sandstone, blue calcareous, varying locally to arenaceous shale; quarried, - - - - - - - -	8′
5. Blue shale, - - - - - - -	15′
	52′

Some closely related exposures on a small creek about a mile west of Belfast are especially instructive. Beginning near the mouth of the stream and following up its course the following sections were taken a quarter of a mile apart. In the intervening spaces, the rocks are not exposed.

V. SECTIONS NEAR BELFAST.

A.

1. Concealed.	
2. Sandstone, blue, weathering brown; somewhat thin bedded and micaceous in places; corresponds to the sandstones below Belfast, -	15′
3. Blue argillaceous shale; no geodes, - - - - -	5′+
	20′+

B.

1. Concealed.	
2. Brecciated limestone; light-colored, - - - - -	8′
3. Brown magnesian limestone, concretionary, some layers more compact; blue, - - - - - - - -	12′
4. An irregular bed of fragmentary limestone and shale, more or less arenaceous, - - - - - - - -	6′
5. Blue argillaceous shale, equivalent of No. 3 above, - - -	1′
	27′

C.

1.	Concealed.	
2.	Hard, white granular limestone in thin flaggy beds; the lower layers contain grains of quartz, - - - - - -	12′
3.	Hard, compact gray limestone, breaks with conchoidal fracture, -	10′
4.	Brown magnesian limestone in thick, somewhat undulating beds, -	10′
		32′

Taking the blue shale as a guide, it is evident that the sandstone in Section A has graded into the magnesian limestones in Section B. In Section C the compact and granular limestones replace the brecciated beds of Section B. The compact limestone is identical with the fragments composing a large part of the brecciated rock and evidently represents an undisturbed portion of the original formation.

Some excellent exposures of the Saint Louis limestones occur near the mouth of Rock Creek:

VI. ROCK CREEK SECTION.

1.	Concealed.	
2.	Hard, gray compact limestone; contains *Rhynchonella ottumwa, Spirifer, Keokuk var. littoni,* - - - - -	6′
3.	Brown, friable quartzose sandstone, - - - -	4′
4.	Brecciated limestone, - - - - - -	20′
5.	Brown, magnesian concretionary limestone in massive beds; contains *Lithostrotion canadense,* - - - - - -	15′
6.	Bed of blue sandy shale, blue grit sandstone, and buff-colored magnesian limestone confusedly mixed together; fragments of chert imbedded in the arenaceous shale, - - - - - -	6′
7.	Blue shale interbedded with thin layers of blue fossiliferous limestone,	16′
		61′

The lower bed (No. 7) is referred to the Warsaw shales. The sandstone No. 3 develops locally to twenty and twenty-five feet, while opposite Keosauqua it contains considerable quantities of calcareous matter and, in places, thin ledges and fragments of limestone. The compact limestone above increases to about fifteen feet in thickness near Keosauqua, where it is quarried to some extent. The heavy-bedded concretionary limestones, No. 5, graduate locally into arenaceous limestones and calcareous sandstones. This gradation may be observed in the basal portion in tracing the formation along the bluffs below Keosauqua. At

Price's quarry, on a small branch of Chequest Creek, west of Pittsburg, and on Bear Creek opposite Bentonsport, the sandstones of this horizon are sufficiently developed to furnish a good quarry stone. It consists of blue calcareous sandstone which weathers brown on exposure. In places it is more or less magnesian.

Correlation.—In Van Buren county, the arenaceo-magnesian beds constitute the base of the Saint Louis group. They have a greater development there than in Lee county where they are replaced partially or wholly by the brecciated limestone. They are represented at Keokuk, Warsaw, Sonora (Ill.) and elsewhere by arenaceous beds originally included in the Warsaw group.

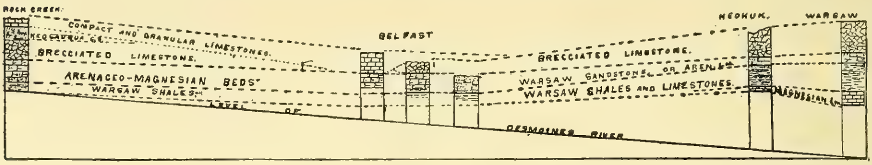


FIG. 2.—Correlation of sections at Warsaw, Keokuk, Belfast and Rock Creek.

The relation of the various beds is shown in the following combined section (Fig. 2) of exposures at Warsaw, Keokuk, Belfast and Rock Creek, while the accompanying table shows the classification here adopted compared with those previously given.

CLASSIFICATION OF THE FORMATIONS OF THE KEOKUK AND SAINT LOUIS GROUPS.

<table>
<tr><th>Gordon</th><th>FORMATIONS</th><th>Hall</th><th>White</th><th>Keyes</th></tr>
<tr><td>L. C. M.</td><td>LOWER COAL MEASURES</td><td>L. C. M.</td><td>L. C. M.</td><td>L. C. M.</td></tr>
<tr><td rowspan="2">Saint Louis</td><td>Compact and Granular Limestones
(Keosauqua S.S.)
Brecciated Limestone</td><td>St. Louis</td><td rowspan="3">Saint Louis</td><td>St. Louis</td></tr>
<tr><td>Arenaceo-Magnesian Beds</td><td rowspan="2">Warsaw</td><td rowspan="4">Keokuk</td></tr>
<tr><td rowspan="3">Keokuk</td><td>Warsaw Shales and Limestones</td></tr>
<tr><td>Geode Shales</td><td rowspan="2">Keokuk</td><td rowspan="2">Keokuk</td></tr>
<tr><td>Keokuk Limestone</td></tr>
</table>

CHARACTERISTICS OF THE FORMATIONS.

The Warsaw shales and limestones.—A consideration of the given sections will show that, at the original locality, the Warsaw group consisted of three members, viz., a bed of magnesian limestone at the base, arenaceous limestone or calcareous sandstone at the top with argillaceous shales, including thin and variable beds of limestone between. Of these the last is the most persistent. The basal division which is twelve feet thick at Warsaw diminishes to three or four feet at Keokuk and is not recognized north of that place. The middle division, however, unchanged in character but greatly diminished in thickness, is recognized at Farmington, Rock Creek and doubtfully at several other localities. The shales and limestones evidently thin out entirely near the north line of Lee county. The formation is prominently characterized by Bryozoa, among which species of Archimedes, Fenestella and other reticulated forms are conspicuous. With these are associated other forms constituting a somewhat peculiar assemblage of fossils, though on the whole allied to those of the Keokuk group. In the Illinois reports, the peculiarity of the fauna is admitted but is considered of somewhat local development, and is attributed to local conditions of sedimentation rather than to any specific change in the character of the fauna. A somewhat similar assemblage of fossils at Bloomington and Spergen Hill, Indiana, was referred to by Hall as proving the existence of these beds in that state. As later collectors have referred the fossils obtained from these beds to the horizon of the Saint Louis limestone without specific designation of the beds from which they were obtained, new collections must be made before the exact relations of these deposits can be considered established.

Evidently, however, the formation is not of wide extent and probably represents only a comparatively local development of the geode shales into which they grade below. It is suggestive in this connection that the geode shales have their most characteristic development coincident with that of the Warsaw shales and limestones, and both soon lose their distinctive characters

and are traced with difficulty toward the south. The oölitic limestone of Monroe county, Indiana, generally correlated with this formation, has been found to occur in an oblong basin or trough, pointing to local sedimentation.

Arenaceous Limestone of the Warsaw.—The arenaceous member at the top of the original Warsaw group has evidently been the source of much of the confusion in the stratigraphy of this region. At Keokuk, it consists of a blue calcareous sandstone in a single massive bed eight feet thick. It contains large white quartz grains scattered through the finer arenaceous material, the whole being firmly cemented by a large amount of calcareous matter. Locally, the quartz grains become large enough to be called pebbles. With the decrease of the arenaceous element, the rock grades gradually through arenaceous to magnesian limestone. All of these phases may occur together in alternate bands. As a whole, the rock weathers to a characteristic brown from the oxidation of the iron, which takes place more rapidly in the arenaceous parts, giving the rock a banded appearance. At Sonora quarry, four miles below Nauvoo, this formation is well developed. It becomes more shaley toward the north end of the quarry and grades horizontally into brown, cellular magnesian limestone. At the Pontoosac quarries above Niota, Ill., the formation has a maximum development of forty feet at one point in the quarry, rapidly diminishing away from this locality to about fifteen feet. Though having the appearance of a sandstone, and called such, analysis shows it to contain only 7 per cent. of sand, a like proportion of clay, and 60 per cent. carbonate of lime, while the remainder is undetermined, but probably consists principally of magnesian carbonate. Cavities lined with spar and sometimes containing Millerite, are occasionally found in the lower part. In places the arenaceous character is replaced by hard, bluish magnesian limestones. The formation rests upon blue shale of which thirty-three feet was penetrated by drill. The surface of the shale is noticeably irregular and the demarkation between it and the formation above is pronounced. At Deamude's quarry, the character of the formation is very sim-

ilar to that at Pontoosac. The sandstones at the same horizon on Bear and Price's creeks in Van Buren county differ in no important respect from those in the vicinity of the Mississippi.

The brown magnesian limestones.—At numerous places on the Des Moines River and its tributaries above Belfast, brown magnesian concretionary limestone is seen resting upon the Warsaw shales and limestones, though separated from them by a more or less disturbed layer of soft, earthy limestone and arenaceous shale inclosing fragments of chert. The magnesian limestones are disposed in thick undulating beds, and contain considerable concretionary chert. These chert nodules average about one to two inches in diameter, and on the decay of the limestone show a thin layer of green clay lining the cavity inclosing the nodule. The nodules usually contain fossil remains in abundance, generally in a fragmentary condition, though the limestone in which they occur may show very little indication of life. The limestone is usually blue on first removal, but quickly oxidizes to a rusty brown color. In texture, the rock is usually more or less vesicular but varies to a compact somewhat earthy limestone. The latter phase especially characterizes one or two thin ledges. These ledges break down more rapidly on exposure and do not weather brown as in the case of the more vesicular portions. The latter become arenaceous locally, as on the Des Moines below Keosauqua, and on Lick Creek above Kilbourne. At the latter place, the indications of cross bedding are marked. The arenaceous element is observed chiefly in the lower beds. The lowest bed is marked frequently by a large proportion of siliceous matter in irregular masses. These masses are nearly pure white silica and are sometimes disturbed and worn as if by wave action subsequent to consolidation. The greatest thickness of these limestones observed is twenty feet. On Chequest Creek, they are seen to grade upward into a compact, buff-colored limestone known locally as Chequest marble. *On Price's Creek west of Pittsburg, the lower layers grade horizontally into well marked sandstone indistinguishable from the arenaceous limestone of the Warsaw beds at Belfast, Sonora and elsewhere.* The brown limestones are marked

by the presence of the well known and characteristic coral *Lithostrotion canadense*, but this fossil has not been observed in the arenaceous portions. An analysis of the magnesian limestone by Owen[1] shows it to be a nearly pure dolomite, consisting of 56 per cent. carbonate of lime and 37 per cent. carbonate of magnesia. Additional analyses are now being made of these and associated rocks by the Iowa survey.

Compact gray limestones.—Overlying the magnesian limestones at Belfast and on Price's Creek, but usually separated elsewhere by the brecciated formation, is a white or bluish gray compact limestone which breaks with conchoidal fracture, and is usually characterized by brachiopods in greater or less abundance. Among these *Spirifera Keokuk, var. littoni, Rhynchonella ottumwa, Productus tenuicostus* are common. The limestone is a nearly pure carbonate of lime, fine grained and brittle, and corresponds in nearly every particular with the character of the Saint Louis limestone as originally described by Shumard. It is sometimes affected by considerable quantities of nodular chert, in consideration of which Owen termed it the Upper Concretionary limestone. In thickness this formation does not usually exceed fifteen feet.

That portion of these beds which rests directly upon the magnesian limestones on Price's Creek, while in the main similar to the higher strata, differ in being of a darker color, and it is from one of these that the "Chequest marble" is obtained, a block of which was the contribution made by the citizens of Van Buren county to the Washington monument.

Granular limestone.—Associated with the compact limestones in places is a formation of granular white or gray limestone which is remarkable for the pronounced exhibition of cross bedding and ripple marks. These beds evidently represent the limestones from this region which have been described as oölitic, but they are rather of a granular or sandy texture. In some places they contain grains of quartz, though for the most part composed of nearly pure carbonate of lime. Intercalated with the thin flaggy

[1] OWEN, D.D.: Geol. Surv. Wis., Ia. and Minn.

layers of granular limestone, however, one or more thin beds of a purer, fine and compact limestone occur which are especially valuable for the manufacture of lime. The granular limestones are well exposed at Graner's quarry (p. 295) and elsewhere. At Belfast they are seen resting upon the compact limestones, the whole constituting a thickness of twenty-two feet. This formation is sometimes found in small lenticular patches in the brecciated limestone, and in some cases a limited development of true oölitic limestone occurs under similar conditions, but it is not common.

Brecciated limestone.—This constitutes the most generally recognized phase of the Saint Louis group in Iowa. Usually it consists of ten to twenty feet of limestone breccia or conglomerate in which the fragments are of the compact variety noted above, more or less completely cemented by similar calcareous material. In its maximum development it is from 50 to 75 feet thick, the brecciated character in these cases evidently involving all of the preceding formations to the base of the Saint Louis group. In these exposures, as, for example, near the mouth of Reed's Creek in Van Buren county, at Croton, and elsewhere, the lower portion is seen to consist of coarse fragments of the arenaceo-magnesian limestones, and their related sandstones, loosely piled together, and the interstices filled with green clay. The whole takes on a rude stratification, while somewhat persistent but decidedly undulating beds occur at irregular intervals. Upwards the breccia becomes more compact and firmly cemented, and is composed chiefly of the compact white or gray limestones sometimes including the granular type. Away from these areas of greatest disturbance, the lower portion is soon replaced by undisturbed strata of the brown Lithostrotion formation while over this the lighter colored, more compact breccia extends itself in varying thickness. It fails entirely in places, as already noted, and its place is occupied by the compact gray limestones in undisturbed beds. These limestones differ from those which elsewhere rest *upon* the brecciated formation in being of a somewhat darker shade. The fragments of limestone composing the breccia are frequently waterworn, but the wearing has seldom

proceeded very far. In some places it may, with propriety, be called a limestone conglomerate, but from the more or less angular character of the fragments the term breccia is more generally applicable. In some exposures thin lenticular beds of breccia, identical in every respect with the main formation, are intercalated between thick layers of the brown concretionary limestone.

The most prominent fossil found in the brecciated limestone is *Lithostrotion canadense*, though this is not abundant, and occasionally another coral like *L. proliferum*. The latter has also been found in the compact limestones at the horizon of the brecciated formation, where this formation is absent. The brecciated limestone characterizes the Saint Louis throughout nearly the whole of its extent in southeastern Iowa. Except where removed by erosion, and at a few localities (Section V.) where it appears never to have been formed, it constitutes a prominent feature of nearly all the rock exposures in Lee and Van Buren counties. It varies in thickness from five to seventy-five feet, but is usually ten to twenty feet thick.

Keosauqua sandstone.—In the area occupied by the Oxbow bend of the Des Moines, a bed of rather coarse brown more or less friable sandstone is intercalated between the brecciated limestone and the compact gray limestone above. Below Keosauqua it is seen at several places resting upon the brecciated formation with a greater or less thickness of the compact limestone resting upon it. Above that place it is seen in the south bank of the river but little above the level of the water where the basal portion is composed in part of isolated layers of limestone inclosed in the sandstone. Opposite Keosauqua the deposit is much disturbed both in character and stratification, in some cases having a large amount of fine calcareous material mingled with the sand which is very irregularly lithified, while in other cases it contains occasional beds of limestone. The overlying limestone has been removed by erosion in some places, leaving the sandstone at the surface. The area thus exposed, however, is small. In some cases the removal took place prior to the deposition of the Coal Measures so that now these formations rest

directly upon the sandstone. An exposure of this kind occurs on Coates Creek about four miles north of Bonaparte. In thickness the formation varies from a few feet to twenty or twenty-five feet.

The area over which this deposit is recognized is limited. It is not known outside of Van Buren county except at one locality in Lee shown in Section III. (p. 294). In Van Buren county the sandstone appears to be directly related to the Bentonsport arch, evidently lapping up against it in the form of an off-shore deposit and thinning out away from the axis of uplift. In origin and occurrence it is clearly related to the brecciated limestone and is seemingly only a phase of that formation due to local conditions attending deposition. The relations of the various beds is shown in the accompanying hypothetical section from south to north.

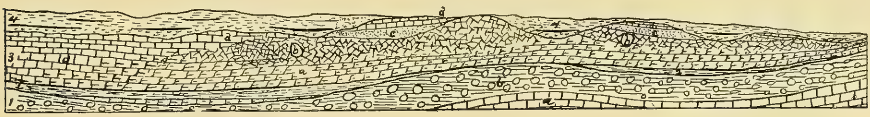


FIG. 3.—Section from south to north showing the relations and variations of the Saint Louis limestone: (1) Geode bed (Keokuk). (2) Warsaw shales and limestones (Keokuk). (3) *a.* Arenaceo-magnesian beds, *b.* Brecciated limestone, *c.* Keosauqua sandstone, *d.* White or gray compact and granular limestones. (4) Lower Coal Measures.

UNCONFORMITIES.

Unconformity below the Saint Louis.—It has been shown by White[1] that while the borders of the Kinderhook, Burlington and Keokuk formations recede, showing a gradual withdrawal of the sea to the south, the Saint Louis limestone overlaps these and reaches nearly as far north as does the Kinderhook. "Consequently these beds (Saint Louis) are recognized as resting unconformably upon all the rest of the Lower Carboniferous in Iowa."[2]

Hitherto no evidence of unconformity at this horizon has been reported from southeastern Iowa. In the nature of the

[1] Geology of Iowa, 1870, Vol. I., p. 226.

[2] C. R. KEYES has recently found beds with typical Burlington crinoids and other fossils in Keokuk, Marshall and Humboldt counties, proving the extension of these beds nearly to the Minnesota line. Hence the overlap of the Saint Louis is probably not so great as White supposed it to be.

case the evidence would be imperfect since the southern boundary of the state apparently marks the extreme limit to which the sea withdrew at the close of the Keokuk epoch. At several localities, however, we have noted a disturbance in the stratification at the base of the arenaceo-magnesian beds which apparently represents the break referred to. It is usually marked by a confused commingling of arenaceous, shaley and calcareous material inclosing fragments of chert, broken shells, etc. It appears in the Rock Creek section (p. 297) and at several other places in Van Buren county, also on East Sugar Creek in Lee county. The arenaceous deposits of the arenaceo-magnesian beds are also sometimes marked by small quartz pebbles in a more or less calcareous matrix, while the cross bedding in the sandstones indicate proximity to the shore line or at least shoal water.

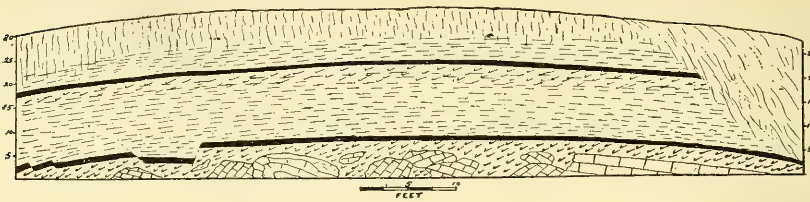


FIG. 4.—Section on Bear Creek, Van Buren county (Sec. 10, T. 68, N. R. 9, W.), showing unconformity of Lower Coal Measure upon Saint Louis limestone.

Moreover, the manner in which the Warsaw shales and limestones below thin out northward offers confirmatory evidence of unconformable relations.

Unconformity above the Saint Louis.—At the close of the Saint Louis epoch the sea again receded, evidently quite rapidly, leaving no enduring evidence of the next succeeding formation (Kaskaskia) which lies 100 miles south of the Iowa boundary. During the Kaskaskia epoch the Iowa region was subjected to extensive erosion, and, on the irregular surface thus formed, the Coal Measure formations were subsequently deposited. Exposures showing this erosion unconformity occur at numerous places in southeastern Iowa. Figure 4 represents an exposure of this character on Bear Creek. The Coal Measure rocks are

here seen resting upon the granular limestones which show various stages of disintegration and decomposition. The clays resting upon the limestones and filling the interstices between the oxidized limestone fragments is evidently the residual product of the decay of the limestones.

About one-half mile west of Rock Creek quarry, the shales of the Coal Measures rest upon the magnesian limestone of the arenaceo-magnesian beds, apparently indicating a channel of erosion at this point (Fig. 5).

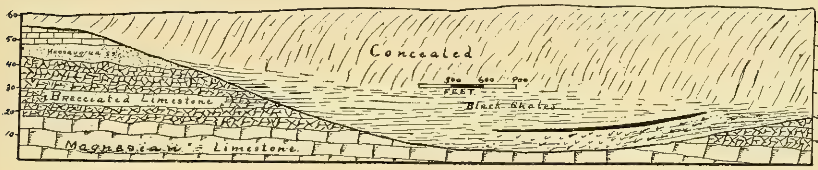


FIG. 5.—Section near the mouth of Rock Creek (Sec. 21, T. 69, N., R. 9, W.) showing eroded surface of the Saint Louis limestone.

One of the best exposures is at the Sonora quarries where the brecciated limestone is entirely cut out by the descent of the Coal Measure rocks (Fig. 6).

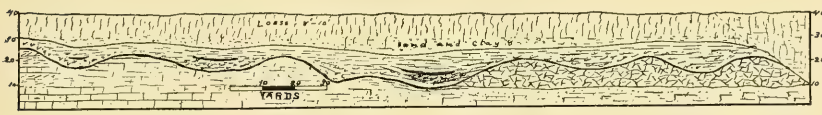


FIG. 6.—Section along face of Sonora (Ill.) quarry showing unconformity of Coal Measures upon Saint Louis limestone.

ORIGIN OF THE BRECCIATED CHARACTER OF THE SAINT LOUIS LIMESTONE.

The origin of the brecciated character often prevalent in limestone formations has never been satisfactorily explained. The explanations that have been offered are:

(1) Wave action upon a rock-bound coast.

(2) The systematic alternation of vigorous and quiet action

of wind waves taken in connection with tidal oscillation in regions where the sea bottom is subjected to wave action at low tide.

(3) Wave action especially facilitated by the development of coral reefs.

None of these is sufficient alone to account satisfactorily for the brecciated limestone of the Saint Louis beds, though in each case favored to a certain extent by the character of the formation. The existence of coral reefs contemporaneous with the formation of this deposit, though not clearly proven, is supported by many structural details. In lithological character there is a striking likeness between these deposits and those of modern coral reefs so well described by Dana. Professor Chamberlin has described a similar character of sedimentation in the Niagara limestone of Wisconsin[1] which he ascribes to a like origin. The abundance of life which characterizes the Niagara reefs in Wisconsin, however, does not appear in the brecciated areas of the Saint Louis limestone in Iowa. While corals are present, they are not especially abundant and no coralline masses standing as they grew have been observed.

The alternations sometimes seen between the brecciated and undistributed portions apparently favors the view that the sea bottom suffered an alternation between vigorous and quiet conditions during the time of its deposition. This may be ascribed (1) to oscillations of the earth's crust, or (2) to tidal oscillation where the sea bottom lies just below low tide.

While crustal movements were evidently in progress during the Saint Louis epoch, the acceptance of this view to account for these minor changes would imply a delicacy of adjustment scarcely in harmony with the character of the forces involved. Professor Chamberlin has called attention[2] to the effect of systematic alternation of wind waves taken in connection with tidal oscillation in accounting for the formation of brecciated limestone. In those areas where the depth of water is such that the sea bottom

[1] Geology of Wisconsin, Vol. I., pp. 183–186.

[2] Geology of Wisconsin, Vol. I., p. 168.

is subjected to wave action at low tide it is conceivable that the alternation of forcible and quiet action might constitute an essential factor in the formation of extensive sheets of brecciated limestone. In its advance upon the land at the close of the Keokuk epoch the sea would doubtless encounter irregularities of the surface, some of the elevations reaching nearly or quite to the surface of the water. The Bentonsport arch apparently represents an area of this character. The first deposits would contain more or less arenaceous material derived from the receding shore. Owing to the prevailing calcareous character of the preceding formations, however, the arenaceous material would be insufficient to constitute a widespread sandstone formation. These conclusions are supported by the lithological character of the arenaceo-magnesian beds, the lower portion of which is generally more or less arenaceous and in places decidedly so. The calcareous mud derived by the trituration of the waves upon those parts of the sea bottom within their reach would be deposited in the quiet lagoons or carried out into deeper water to form the fine-grained compact limestones. As the brecciated formation is made up chiefly of fragments of these fine-grained rocks, it is evident that solidification must have taken place very quickly. The presence of lenticular masses of breccia made up of fragments of these fine-grained white or gray limestones interlaid with the massive brown arenaceo-magnesian beds implies that their formation was going on contemporaneously with the sedimentation of the latter beds. Their isolated occurrence, however, as well as their position below the main mass of breccia is not readily explicable unless they represent the thinning out of local masses exposed by tangential erosion. It has been suggested that similar occurrences were due to transportation by shore-ice.[1] The assumption of this agency, however, would preclude the acceptance of coral growth as a factor in the formation of the brecciated limestone, as it implies conditions of temperature inconsistent with the development of reef-building corals.

[1] WALCOTT, C. D.: Bull. Geol. Soc. Am., Vol. V., p. 197.

Dolomitization.—There is a marked difference in lithological character between the arenaceo-magnesian beds and the overlying limestones. The former are decidedly magnesian and in some cases dolomitic, while the latter are almost entirely calcareous. Where the brecciated bed is absent there appears to be a gradation between the two. The explanations which have been proposed to account for dolomitization are:

(1) Chemical precipitation or sedimentation.

(2) Leaching of carbonate of lime from a magnesian limestone subsequent to solidification.

(3) Replacement of some of the lime by magnesia subsequent to solidification.[1]

From the record of observations it seems probable that all of these processes have taken place. With regard to the first view it has been shown by Dana[2] that while "corals themselves contain very little carbonate of magnesia, magnesia is largely present in some specimens of the rock." The coral sand and some of the compact limestones, however, are said to have very little or no magnesia. The conclusion is drawn that the introduction of the magnesian element has taken place (1) in sea waters at the ordinary temperature and (2) without the aid of any mineral waters except the ocean. The change is thought to have taken place in contracting and evaporating lagoons in which the magnesian and other salts of the ocean were in a concentrated state. That dolomite is essentially a littoral deposit has been advocated by Calvin,[3] while Geikie says that while some dolomites may have been formed by chemical precipitation in inland lakes and seas, others may have been formed by the action of magnesian salts of sea water upon organic limestones already formed.[4] The relations of the magnesian and compact limestones in southeastern Iowa favor the conclusion that they were formed under essentially the same conditions. As the magnesian character

[1] HOPKINS, T. C.: Geol. Sur., Ark., 1890, Vol. IV., p. 38.

[2] Corals and Coral Islands, p. 393.

[3] American Geologist, Vol. I., p. 30, and Vol. II., p. 36.

[4] Text-book of Geology, p. 296.

appears more pronounced in areas affected by brecciation and has not been noted as far south as St. Louis, there is a strong presumption that the conditions attending the formation of brecciated limestone exercised a controlling influence in effecting the transformation of the rock. The limestone of the Niagara reefs of Wisconsin are dolomitic, as indeed are nearly all those found in that state.[1] The available evidence, therefore, is apparently in favor of Calvin's conclusion that dolomites are essentially off-shore products.

C. H. GORDON.

[1] Geology of Wisconsin, Vol. I., p. 303.

ALGONKIAN ROCKS OF THE GRAND CANYON OF THE COLORADO.

CONTENTS.

INTRODUCTION.

The Algonkian rocks of the Grand Canyon are unique among the known unconformable pre-Cambrian rocks both of America and of Europe. Nowhere else has the geologist an equal opportunity to study such a series of ancient sediments nearly as they were laid down on the bed of the Algonkian sea. At no other known locality are there such extended and complete exposures of all the beds forming a great series of pre-Cambrian strata, permitting of such certainty in the determination of stratigraphic position and succession.

The first recorded notice of these rocks is that by Major J. W. Powell in the account of his famous explorations of the Colorado River of the West and its tributaries. He says in his report of 1875, page 212, that above the granites there are beds of hard, vitreous sandstone, of many colors, that add but little more than 500 feet to the height of the walls, and yet, owing to their nonconformity with the overlying Carboniferous rocks, they are 10,000 feet in thickness. On page 213 we learn that the rocks unconformably beneath the sandstone series are composed of metamorphosed sandstones and shales which have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GEOLOGICAL MAP
of the
111°50'
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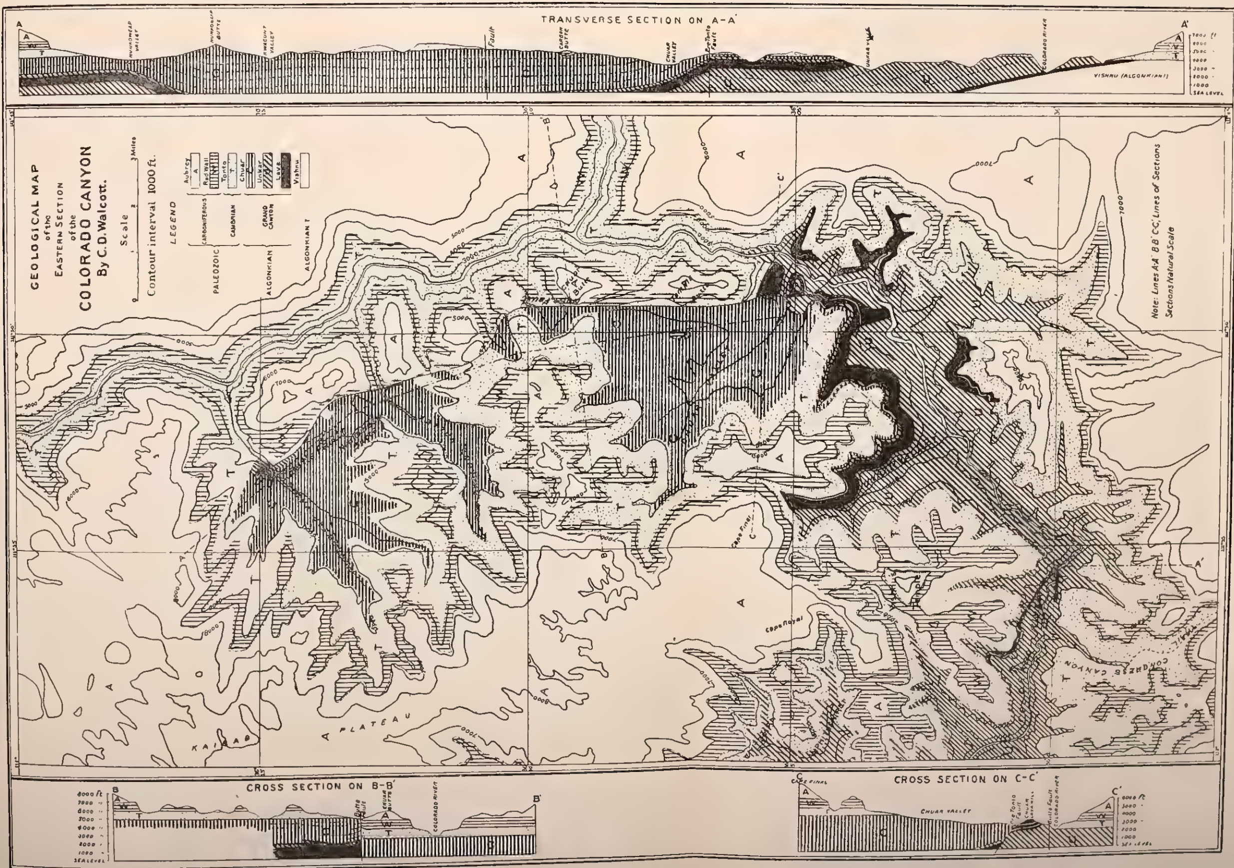
112°


TRANSVERSE SECTION ON A-A'
GEOLOGICAL MAP
of the
EASTERN SECTION
of the
COLORADO CANYON
By C. D. Walcott.
Scale
3 Miles
Contour interval 1000 ft.
LEGEND
Aubrey
Red Wall
Tonto
Chuar
Unkar
Lava
Vishnu
CARBONIFEROUS
CAMBRIAN
GRAND CANYON
PALEOZOIC
ALGONKIAN
ALGONKIAN ?
Note: Lines A A' B B' C C' Lines of Sections
Sections Natural Scale
KAIBAB
PLATEAU
CONGRESS CANYON
CROSS SECTION ON B-B'
CROSS SECTION ON C-C'
CHUAR VALLEY
COLORADO RIVER
VISHNU (ALGONKIAN?)

been folded so many times, and so squeezed and heated, that their original structure as sandstones and shales is greatly obscured or entirely destroyed. Further, after these beds were deposited, after they were folded, and after they were deeply eroded, they were fractured, and through the fissures came floods of molten granite, which now stands in dikes, or lies in beds, and the metamorphosed sandstones and shales and the beds of granite present evidence of erosion subsequent to the periods just mentioned yet antecedent to the deposition of the nonconformable sandstones.

In a report on the geology of the eastern portion of the Uinta Mountains, etc., 1876, page 70, Major Powell's summary of the Grand Canyon Group is as follows:

> The Grand Canyon Group rests conformably upon the crystalline schists. The evidence of this is complete, for the lower sandstones and conglomerates first filled the valleys and then buried the hills of schistic rocks, and these conglomerates at the base of the group are composed of materials derived from the metamorphic hills about; and hence metamorphism was antecedent to the deposition of the conglomerates.
>
> The plane of demarkation separating this group from the Tonto Group is very great. At least 10,000 feet of beds were flexed and eroded in such a manner as to leave but fragments in the synclinals. Then followed a period of erosion during which beds of extravasated material were poured over the fragments, and these igneous beds also were eroded into valleys prior to the deposition of the Tonto Group.
>
> Fossils have been found at the base of the Grand Canyon series, but they are not well preserved and little can be made of them. Still, on geological evidence, I am of the opinion that these beds should be considered Silurian.

The subjacent Grand Canyon schists are referred to the Eozoic. This is followed by a statement that the grouping should be considered merely tentative; that it may need some modification, or possibly radical changes.

When describing the unconformity between a horizontal series of rocks forming the upper 4000 feet of the canyon walls and the subjacent unconformable series, Captain C. E. Dutton stated, in his Tertiary History of the Grand Canyon District, 1882, page 179, that the thickness of the lower series must be very great—at least 6000 feet, that Major Powell's estimate of 10,000 feet is

apparently justified, and that the age of the series is probably Silurian; also that Devonian beds may be found in its upper part, but all that he could say then was that they are pre-Carboniferous. He called attention to some layers among the higher beds of the series which he did not hesitate to pronounce volcanic rocks—basalts or diabases. They are coal black and interbedded with the Upper Silurian (?) strata, but whether they are intrusive sheets or contemporaneous coulées outpoured while the rocks were accumulating, he could not say.

During the winter of 1882–83 I studied in detail the Grand Canyon series of Powell, and found that it was, as stated by the latter, unconformably beneath the Tonto sandstone. The lava beds, however, were found to be interbedded and contemporaneous with the deposition of the Grand Canyon terrane and 6000 feet below the summit of the series. In a preliminary note published in 1883, the Grand Canyon series of Powell is divided into a lower or Grand Canyon group and an upper, the Chuar group.[1]

As traces of fossils were found in the Chuar terrane, it and the Grand Canyon terrane were referred to the Lower Cambrian. The subjacent unconformable strata were referred to the Archean, and by reason of stratigraphic position they were tentatively correlated with the Keweenawan group of Wisconsin.[2]

In 1886 the Grand Canyon and Chuar terranes were referred to a pre-Cambrian series of rocks;[3] and in 1890, in describing the Butte fault, a diagrammatic section[4] and several detailed sections that included portions of the Chuar and Unkar terranes were published.[5]

In his correlation paper on the Archean and Algonkian rocks,[6]

[1] Pre-Carboniferous strata of the Grand Canyon of Colorado: Am. Jour. Sci., Vol. XXVI, 1883, p. 440.

[2] *Loc. cit.*, p. 441.

[3] Am. Jour. Sci., Vol. XXXII, 1886, p. 144; Bull. U. S. Geol. Survey No. 30, 1886, p. 41.

[4] Tenth Ann. Rept. U. S. Geol. Survey, 1890, p. 551.

[5] Bull. Geol. Soc. Am., Vol. I, 1890, pp. 51–56.

[6] Bull. U. S. Geol. Survey No. 86, p. 507.

Professor C. R. Van Hise gives a summary of the Algonkian rocks of the Grand Canyon of the Colorado, based upon the observations of Powell, Dutton, and Walcott.

GEOGRAPHIC POSITION AND DISTRIBUTION.

That portion of the Grand Canyon of the Colorado in which the Unkar and Chuar terranes and the typical section of the Vishnu terrane of the Algonkian (?) series or rocks are exposed, is situated in northern Arizona, between 36° and 36° 17′ N. latitude and 111° 47′ and 112° 05′ W. longitude. Most of this area is in the valley portion of the canyon, between the mouth of Marble Canyon and a point south of Vishnu's Temple, a little west of where the Colorado River changes its course from south to northwest. It is wholly within the greater depths of the Grand Canyon, east and southeast and south of the Kaibab plateau. The inter-canyon valleys of this portion of the Grand Canyon extend back from three to seven miles west of the river, and are eroded in the crest of the monoclinal fold that forms the eastern margin of the Kaibab plateau. All of the valleys have small lateral canyons that lead into them from the high margin of the plateau. The Chuar terrane is confined almost entirely to the inter-canyon valleys of Nunkoweap, Kwagunt, and Chuar, as shown on the map (Pl. VI.). About four miles below the mouth of the Little Colorado the Unkar strata rise above the river, and rapidly expand so as to form the inner-canyon beneath the Tonto sandstone for a distance of eleven miles down the westward bend of the river, south of Vishnu's Temple. A small outcrop also occurs on the line of the Butte fault, at the lower end of Nunkoweap Valley. In going down the river the Vishnu rocks are first seen south of Vishnu's Temple (36° N. lat., 111° 55′ 30″ W. long.), and they appear to extend down the river to the southwestern side of the Kaibab plateau, nearly to Surprise Valley (lat. 112° 33′). Whether the pre-Tonto rocks near the mouth of the Grand Canyon are a portion of the Vishnu terrane is unknown.

NOMENCLATURE.

The name "Grand Canyon Group" was given by Major J. W. Powell to the series of strata beneath the Tonto sandstone and above the "Grand Canyon Schists." The latter were referred tentatively to the Eozoic,[1] and the 10,000 feet of the "Grand Canyon Group" to the Silurian. Captain Dutton regarded the series as of pre-Carboniferous age, and probably Silurian.[2]

In 1883 I referred the Grand Canyon series of Powell to the Lower Cambrian, and divided it into a lower and an upper group —the "Grand Canyon" and "Chuar," respectively,[3] the name "Chuar" being proposed by Major Powell.[4] In 1886 the reference to the Lower Cambrian was changed to a pre-Cambrian series of rocks,[5] and correlations were made with the Keweenawan series of the Lake Superior region.[6] In a section of the strata of the Grand Canyon District published in 1890, the pre-Tonto strata were referred to the Algonkian group, under the names Chuar, Grand Canyon, and Vishnu, the latter including the strata unconformably beneath the Grand Canyon group.[7]

At the present time it appears to be necessary to return to Major Powell's name, Grand Canyon,[8] as applied to the entire series of strata between the Tonto and the "Grand Canyon Schists," and to give to the lower series the name Unkar, from the valley in which its finest exposures occur. The name Vishnu is retained for the unconformably pre-Unkar strata. The classification, from the Tonto down, will then be:

[1] Geology of the Eastern Portion of the Uinta Mountains, 1876, p. 70.

[2] Tertiary History of the Grand Canyon District, 1882, p. 180.

[3] Am. Jour. Sci., Vol. XXVI., 1883, p. 439.

[4] *Loc. cit.*, p. 440.

[5] Bull. U. S. Geol. Survey No. 30, 1886, p. 41.

[6] Am. Jour. Sci., Vol. XXXII., 1886. pp. 144, 153–157.

[7] Bull. Geol. Soc. Am., Vol. I., 1890, p. 50.

[8] Changing the spelling of "Cañon" to Canyon, in conformity with the decision of the Board on Geographic Names.

CAMBRIAN.	Tonto.	
Unconformity.		
ALGONKIAN.	Grand Canyon.	Chuar. Unkar.
Great Unconformity.		
ALGONKIAN (?)	Vishnu.	

STRATIGRAPHIC RELATIONS.

The stratigraphic relations of the Cambrian, Algonkian, and the doubtful Vishnu beds are indicated by the preceding tabulation, and are clearly shown by section A—A′ of the map. Within the Algonkian series there is no recognized interruption in sedimentation between the base of the Unkar terrane south of Vishnu's Temple and the summit of the Chuar terrane at Nunkoweap Butte, with the exception of a slight unconformity by erosion at the summit of the Unkar terrane. At the base of the Unkar terrane there is a bed of conglomerate that rests unconformably on the eroded edges of the indurated sandstones, micaceous schists, and granitic dikes. The unconformity is absolute. (Fig. 1).

From the base of the Unkar terrane south of Vishnu's Temple the strata dip 10° to the northeast, and then, as shown on the map (Pl. VI. and the accompanying section), they flatten out on the line of the divide between Unkar and Chuar Valleys, dip 25° to the north in the heart of Chuar Valley, and thence extend in low, broad undulations to the syncline of Nunkoweap Butte. North of the Butte the strata rise, the dip being from 20° to 25° southeast. The summit of the series is at Nunkoweap Butte, between Kwagunt and Nunkoweap Valleys. From the point south of Vishnu's Temple to where the strata of the Chuar terrane pass beneath the basal beds of the Tonto sandstone, on the north side of Nunkoweap Valley, there is a marked unconformity between the strata of the Grand Canyon series and the superjacent

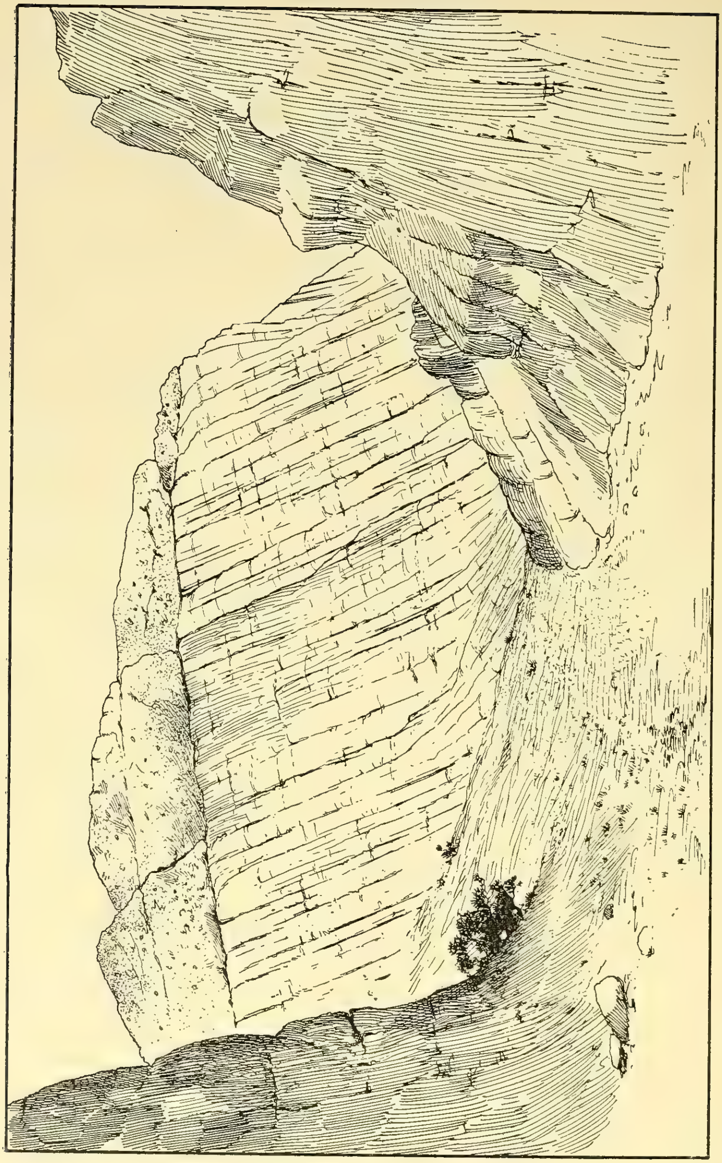


FIG 1. Unconformity at the Base of the Unkar Terrane. Conglomerates resting on the upturned, eroded Beds of the Vishnu Terrane.

Cambrian sandstone. The former were planed off to a baselevel before the deposition of the latter.

CHUAR TERRANE.

The first division of the Chuar terrane is from the summit of Nunkoweap Butte, on the divide between Nunkoweap and Kwagunt Valleys, down the south side of the butte to the base of a massive belt of reddish-brown sandstone. The latter stratum was traced to Chuar Valley, where it caps the lower division of the terrane on the north side of the valley. The lower division terminates in argillaceous shales resting on a massive magnesian limestone south of Chuar Brook.

Section from the Summit downward.

UPPER DIVISION.

	Feet.	Feet.
1. *a.* Massive reddish-brown sandstone, with irregular layers of similar color and containing numerous fragments of sandstone-shale of lighter color - - - -	125	
b. The sandstones of 1 become shaly near their base and pass into a reddish, sandy, and then argillaceous shale, with a few thin, compact layers of sandstone in the shale	75	200
2. Black, fissile, argillaceous shale, that crumbles on exposure to the weather - - - - - - -		225
3. Compact gray limestone in massive layers; buff on weathered surface - - - - - - -		50
4. Shale similar to 2 - - - - - -		60
5. Gray limestone similar to 3 - - - - - -		50
6. Black argillaceous shale, similar to 2 and 4 - - -		140
7. Hard buff limestone, with irregular oölitic, cherty bands that at times constitute most of the stratum - -		4
8. *a.* Black argillaceous shale, with compact layers 2 or 3 inches thick - - - - - - -	30	
b. Dark, earthy limestone - - - - -	1	
c. Black shale - - - - - -	2	
	—	33
9. Gray, Stromatopora[1] (?) limestone - - - - -		8
10. Black argillaceous shale, with variegated shales below, containing more or less arenaceous matter in the form of arenaceo-argillaceous shale and thin layers of sandstone.		

[1] Probably a species of Cryptozoon.

	Feet.	Feet.
On the slopes light-drab, pea-green, vermilion, chocolate, maroon, and buff-colored shales of various shades alternate		740
11. Massive stratum of concretionary limestone - -		10–25
12. Reddish-brown, sandy shale - - - - - -		25
13. *a.* Thick-bedded, dark reddish-brown sandstone - -	70	
b. Same, thinly bedded - - - - -	70	
	—	140
Total thickness of upper division - -		1700

The last two beds form so strongly marked a horizon in the shaly beds that it is taken as a rough division line in the terrane, the strata beneath containing a different character of limestone that serves to distinguish them.

LOWER DIVISION.

	Feet.	Feet
1. Brown sandy shales, passing below into chocolate and dark argillaceous shales that alternate with brown and greenish, sandy shales. Near the summit a layer of oölitic iron ore occurs - - - - - - - -		300
2. *a.* Alternating sandy and argillaceous shales, with thin belts of limestone from 6 inches to 4 feet in thickness - -	310	
b. Stromatopora limestone - - - - -	4	
c. Dark shaly limestone - - - - - -	3	
d. Dark argillaceous shale - - - -	6	
e. Dark-gray shaly limestone in massive layers - -	2	
	—	325
3. Chocolate-brown, dull and yellowish-green, sandy and argillaceous shales, with sandstone in narrow bands, and 21 feet of limestone in thin layers near the middle and base of the stratum - - - - - - - -		625
4. *a.* The sandstone and sandy shales become less prominent, the argillaceous and calcareous strata replacing them, 54 feet of limestone occurring in 500 feet of strata - -	500	
b. Dark clay-shale - - - - - -	4⅓	
c. Dark shaly limestone - - - - - -	1	
d. Dark argillaceous shale - - - - -	4	
e. Gray limestone, having a tendency to break up into shaly layers; strongly bituminous near the base - -	5⅔	
f. Friable, rather coarse, gray to buff sandstone - -	5	
g. Compact lead-colored limestone - - - -	2	
	——	522

	Feet.	Feet.
5. Black argillaceous shale, with chocolate and greenish, sandy and argillaceous shales beneath, carrying hard layers of sandstone. In a few localities white and pink gypsum occurs in masses a few feet in diameter, or as seams in the upper, black shales - - - - - - -		100
6. Three feet of compact, mottled, buff limestone interbedded in 15 feet of brown sandy shale - - - -		18
7. *a.* Black and chocolate, sandy and argillaceous shales, with three thin layers of limestone near the base - -	180	
b. Black and brown argillaceous shale, with interbedded layers of a somewhat friable sandstone - - -	180	
c. Chocolate, green, maroon, drab, argillaceous shales, with thin layers of brownish sandstone interbedded, and, toward the base, sandy shales - - - -	360	
d. Brown sandstone, in layers 8 to 18 inches thick, passing below to sandy and argillaceous shales, with layers of buff and chocolate sandstone - - - - -	55	
e. Drab argillaceous shale, passing down into brown, sandy, ripple-marked shales - - - - -	55	
	——	830
8. *a.* Massive band of irregular, thinly bedded limestone, gray and buff except near the chocolate-colored upper stratum. A variety of limestone occurs.		
b. Chocolate-colored, compact layers, with a smooth, partially conchoidal fracture.		
c. Evenly bedded, thin layers, hard, lead-colored.		
d. Thin, shaly, gray layers.		
e. Very irregular and concretionary layers.		
f. Compact, gray, bituminous layers.		
Total - - - - - - -		50
9. Dark argillaceous shale, with a strongly marked band of a deep-maroon color; drab, yellowish-green, and dark or brownish-black shales continue below to a dark-chocolate band that is superjacent to 100 feet of drab and greenish shales. The shales are largely argillaceous, with arenaceous matter scattered through the section as sandy shales, thin-bedded sandstone, and arenaceo-argillaceous shales. In one locality a band of fine-grained gray limestone, 6 inches thick, occurs in the shales 3 inches above the base of the Chuar terrane - - - - - - - - - -		450 to 650
Total thickness of lower division - - - -		3,420

	Feet.
Total thickness:	
Upper division - - - - - -	1,700
Lower division - - - - -	3,420
	5,120
Limestone in upper division - - - - -	138
Limestone in lower division - - - -	147
	285

UNKAR TERRANE.

The line of outcrop of the massive magnesian limestone below the base of the Chuar terrane extends south, in the face of the cliffs, to the north side of Unkar Valley. The section was taken from this point south across Unkar Valley and along the walls of the inner canyon of the Grand Canyon to a point south of Vishnu's Temple, where the sandstones and conglomerates rest unconformably upon the sandstones, schists, etc., of the Vishnu terrane and the gneisses, schists, etc., of the Archean. The section is characterized by a great thickness of reddish-brown sandstones.

Section from the Summit downward.

	Feet	Feet
1. *a.* Massive beds of gray to reddish magnesian limestone, passing below into a calciferous sandrock -	50–150	
b. Light-gray shaly sandstone - - - -	25	
c. Irregular massive beds of yellowish-brown sandstone, -	50	
d. Partially cross-bedded, fine-grained, purplish-brown sandstone - - - - - - - -	50	
e. Reddish-brown sandstone and sandy shales, ripple-marked	200	
		475
2. Lava beds:		
a. Dark-green basaltic rock with a reddish tinge. Breaks into small angular fragments. Upper surface slightly irregular - - - - - -	100	
b. Layers of a reddish-brown sandstone - - -	8–10	
c. Solid, compact lava, of a dark-green and reddish tinge, with a slight tendency to columnar structure - -	70	
d. A layer of sandstone, 1 foot in thickness, caps a massive flow of dark-green lava, which breaks up and weathers into a fine talus of a lighter green than the rock in place	100	
e. A flow not unlike *d*, and capped by a layer of sandstone 2 feet in thickness - - - - - -	70	

		Feet.	Feef.
A layer of vesicular lava with a thin stratum of sandstone at the summit		10	
g. Solid, compact lava, of a dark-green and reddish tinge, with columnar structure partially developed in the central portion. This band appears to be formed of three flows in quick succession, as no sedimentary material accumulated on the surface of the two lower; 25, 125 and 25 feet; total		175	
h. Reddish-brown sandstone, compact and slightly metamorphosed toward the summit		15	
i. On the weathered surface this flow presents a slope of 25° to 30°, rarely forms a cliff, as do the flows above, and the rocks crumble into a rather light olive-green, coarse sand. Thin beds of reddish-brown sandstone occur in several places, and one, 125 feet from the base, is quite persistent in its horizontal extension. The upper surface of the flow is slightly undulating and more or less nodular		250	
		——	800
3. Sandstones (upper):			
a. Shaly, vermilion, rather fine-grained sandstones, with intercalated bands of a greenish-gray, followed below by 700 feet of vermilion beds of a uniform character, and massive beds with arenaceous, shaly partings, the massive beds breaking up into shale and sandstone on the talus slopes. Ripple-marks and shrinkage-cracks characterize the upper, shaly beds		1,730	
b. The vermilion sandstones of *a* pass into chocolate-colored sandstones, that for 125 feet down unite in the general slope of the beds above. Below, a cliff is formed of five massive bands of chocolate-colored, slightly micaceous sandstone, separated by shaly sandstone partings of a greenish color below and a chocolate color above		925	
c. Reddish-brown to chocolate, more or less shaly sandstone, 125 feet, underlain by 300 feet of friable sandstone and arenaceous and micaceous shale		425	
d. Irregularly bedded, compact sandstone:			
Curiously twisted and gnarled layers	15		
Massive, grayish layer	10		
Light-gray layer with reddish spots, friable, shaly in places	125		
	——	150	
		——	3,230

		Feet.	Feet.
4. Sandstones (lower):			
a. Compact, quartzitic, gray sandrock, 25 feet, with 65 feet of hard, compact sandstone		90	
b. Massive, compact, cliff-forming, brown, buff, and purplish-brown sandstone		1,200	
c. 1. Reddish-brown to vermilion, friable, shaly sandstone	200		
2. Brick-red shaly sandstone	250		
3. Brown, friable, shaly sandstone, ripple-marks and shrinkage-cracks	300		
4. Same in more massive layers, with fine, siliceous conglomerate (10 feet) at the base	80		
	──	830	
		──	2,120
5. *a*. Light-gray limestone, with interbedded laminæ of quartzitic shale		8	
b. Brown sandstone, with a bed of siliceous conglomerate, 2 feet		30	
c. Reddish, cherty limestone		10	
d. Reddish-brown limestone		2	
e. Dark reddish-brown slate,		5	
f. Light-gray, compact, shaly limestone		14	
		──	69
6. Dark, compact, basaltic lava in one massive flow			80
7. Light-gray, compact, shaly limestone with pinkish tinge between the laminæ; it is a little cherty near the base, or with thin, hard, interbedded layers of sandstone			26
8. Siliceous conglomerate, formed largely of pebbles derived from the upturned edges of the pre-Unkar strata, upon which it rests unconformably			30
Total thickness of the Unkar terrane			6,830
Total thickness of the Chuar terrane			5,120
Total thickness of Grand Canyon series			11,950

VISHNU TERRANE.

The strata of the Vishnu terrane on the north side of the Grand Canyon, due south of Vishnu's Temple, consist of micaceous schists and quartzite, with dikes and veins of reddish colored granite cutting across the plicated bedding of the schists, etc. I examined this series at one point only, and do not feel warranted in discussing its general characters. On the south

side of the canyon the strata occupying the same relative position beneath the base of the Unkar terrane have been considered to be of Archean age.

SEDIMENTS AND CONDITIONS OF DEPOSITION.

Over the eroded, upturned beds of the Vishnu terrane a bed of siliceous conglomerate, composed largely of pebbles derived from the beds below, indicates the old sea-beach formed during the period preceding the deepening of the water. In this sea sand and a few beds of calcareous mud accumulated prior to the spreading of a flow of basaltic lava which now forms a massive bed 80 feet in thickness. In the period of quiet following the lava-flow, a few alternating beds of calcareous and arenaceous mud and sand were deposited prior to the deposition of 5350 feet of sandy beds, which now form rather fine-grained, vermilion, chocolate, brown, buff, and parti-colored sandstones. With the close of this epoch of arenaceous deposition the sea-bed and the strata beneath were fissured by crevices which extended down into the Archean, and flow after flow of basaltic lava poured out through these over the sea-bed. In the intervals between the flows the deposition of the sand continued, and we now find, between the massive lava-flows evenly distributed beds of reddish-brown sandstone. With the last of the six principal flows the sea deepened, and a thick deposit of calcareous mud was accumulated, which now forms a magnesian limestone, passing below into a calciferous sandrock, the whole varying from 50 to 150 feet in thickness. This was the closing deposit of the Unkar terrane. Its upper surface shows slight traces of erosion, and, as the sediments of the succeeding Chuar terrane are unlike those of the Unkar, it is probable that the source from which the sediments were derived changed from one that had contributed a vast amount of sand to one that yielded great quantities of argillaceous matter and sand of a still finer character. It is not to be understood that this implies a change of source of sediment, but rather a change of conditions, produced by progressive erosion that lowered a somewhat elevated area

toward a baselevel before the close of the known upper limit of the Chuar terrane.

The lithologic characters of the Unkar terrane are rather uniform in the upper portion, the strata consisting of reddish-brown and greenish sandy shales, and of layers of a medium-grained sandstone, varying from 2 inches to 3 feet in thickness. In the more thickly bedded portion there is a tendency to form cliffs that resemble the Triassic sandstones of the Vermilion Cliffs of southern Utah, and the shaly portions are much like those of the Trias. As a whole the prevailing color is a reddish-brown, much like that of the Carboniferous Lower Aubrey sandstone cliffs in the canyon wall, 2000 feet above. Traces of life are as yet unknown; ripple-marks, fine and coarse mud-cracks, and all the markings of quiet, shallow water and a low shore-line that was frequently exposed to the action of both water and air, are abundant.

The sandstones of the Unkar group are exposed directly in the Grand Canyon, below the mouth of Chuar Valley; and the rocks of the Chuar terrane occur in nearly all of the canyon valleys between the eastern side of the Kiabab plateau and the six great buttes that form the west side of the lower portion of Marble Canyon.

As indicated by the section, the Chuar terrane was formed and calcareous muds, uniformly spread over a relatively level sea-by the deposition of a great series of argillaceous, arenaceous, bed. The strata now succeed one another as fine sandstones, shales and limestones, the lithologic characters resembling those of the Cretaceous, as seen in the cliffs a few miles to the north. In places the limestones and shales may be compared with the Trenton limestone and the Utica shale of the Lower Palæozoic of the East. The parti-colored shales, in one belt 700 feet in thickness, recall the friable Permian clays. In fact, there is no more evidence of metamorphism throughout the 12,000 feet of the Grand Canyon series than there is in the evenly bedded strata of the Permian, Triassic, and Cretaceous groups of the Plateau Province of northern Utah.

Midway of the lower portion of the shales and limestones of the Chuar terrane the presence of a fauna is shown by a minute discinoid or patelloid shell, a small Lingula-like shell (which may be a species of Hyolithes), and a fragment of what appears to be the pleural lobe of a segment of a trilobite belonging to a genus allied to the genus Olenellus, Olenoides or Paradoxides. There is also a Stromatopora-like form that is probably organic.

The paucity of the fauna in both the Unkar and Chuar terranes demands some explanation, for the strata were apparently deposited under conditions most favorable to the development of abundant life. I find in my field-notes a suggestion that the sediments were deposited in a great inclosed basin, or mediterranean sea, and that during the greater part of the period of their deposition no connection existed by which any fauna then existing outside of this sea could obtain ingress.

The sediments of the Unkar and Chuar terranes, as measured, give a total thickness of 11,950 feet. How much more was planed away by the sea in which the next terrane (the Tonto) was deposited was not determined. With the close of the epoch of the Chuar terrane a period of orographic movement ensued, during which the strata of the Vishnu, Unkar, and Chuar terranes were elevated, broken by faults, and more or less flexed. The summit of the series is now found in a knoll on the divide between Nunkoweap and Kwagunt Valleys. It may have been a remnant left by the sea as the latter cut away the Algonkian land, or a hill remaining above the baselevel of erosion that planed away a section of the entire thickness of the pre-Tonto strata. The surface upon which the sandstones of the lower Tonto were deposited was nearly level. Here and there a hard stratum caused ridges to be left in the Tonto sea, and the fragments broken from them are scattered among, and mixed with, the sands of the Tonto.

Of the duration of the interval of erosion between the deposition of the sediments of the Chuar terrane and the first of those of the Tonto, we can only form a conjectural estimate, based on the sections of Cambrian rocks in northwestern and central

Nevada. The stratigraphic position of the sandstone at the base of the Tonto terrane is that of the Middle Cambrian, a horizon equivalent to that of the lower portion of the St. Croix sandstone of Wisconsin and the Secret Canyon shale of the Eureka District of Nevada. The fauna of the Chuar terrane indicates the presence of life, but it is not of value in stratigraphic correlations. It is probable, almost to a certainty, that it is older than the Olenellus fauna of Nevada. If this be true, the interval between the summit beds of the Chuar terrane and the Tonto sandstone is represented, in Nevada and Utah, by a deposition of 3000 or more feet of limestones and many thousand feet of sandstones and siliceous argillites. With the exception of a few traces at the base of the Tonto sandstone, none of detrital sediments resulting from the erosion of the pre-Tonto land area have been discovered.

GEOLOGIC AGE.

The lower portion of the Tonto terrane, the Tonto sandstone, forms the base of the Palæozoic section in the Grand Canyon District. It is massive-bedded and rather coarse in the lower portion, passing above into shaly, fine-grained, fossiliferous sandstones. The presence of a well-marked Middle Cambrian fauna in its upper portion clearly indicates its geologic age. It is only the absence at the base of the sandstone of the Lower Cambrian or Olenellus fauna that prevents us from carrying the recognized Palæozoic section down to include its oldest known fauna. The period of erosion represented by the unconformity between the Tonto sandstone and the Grand Canyon series is considered to more than equal Lower Cambrian time, and to constitute a well-defined boundary between the Palæozoic and pre-Palæozoic formations. In my earlier work, in 1883, I referred the Grand Canyon and Chuar strata to the Cambrian;[1] but upon further study of the Cambrian rocks and their contained faunas, and in view of the extent of the time-break indicated by the noncon-

[1] Am. Jour. Sci., Vol. XXVI., 1883, p. 441.

formity by erosion, this was changed in 1886, and all the pre-Tonto strata were referred to a pre-Cambrian series.[1]

In the scheme of nomenclature adopted by the Geological Survey in 1888, the clastic rocks beneath the Cambrian and superjacent to the Archean were grouped under the term Algonkian—of equivalent rank to Cambrian, Silurian, etc.[2] In this classification the system name—equivalent to Palæozoic, etc.—was not decided upon; but I am strongly in favor of adopting the name "Proterozoic," proposed by Dr. Irving and accepted by Professor C. R. Van Hise.[3] Under this nomenclature the Grand Canyon series will be referred to the Algonkian system of the Proterozoic group.

There may be a difference of opinion among geologists as to the adequacy of the evidence that the Grand Canyon series is pre-Cambrian. This can hardly be the case with those who have studied the questions of orographic movement and subsequent erosion. The long section on the map shows most clearly that the sediments of the Grand Canyon series were elevated, faulted, and more or less flexed prior to the period of erosion that cut away a section of the entire series and not only reduced to a baselevel the land area formed by the latter, but reduced to the same plane the more resistant subjacent rocks of the Vishnu terrane of the Algonkian, and probably the Archean, to the west. The time required for the orographic movement resulting in elevation and for the subsequent erosion would exceed, in my opinion, the period of Lower Cambrian sedimentation. It is not at all improbable that the sediments of Lower Cambrian time in the Great Basin region of Nevada, Utah, etc., were derived from the Algonkian continent to the east, of which the Grand Canyon series of rocks then formed a part.

CORRELATION.

The Grand Canyon series, the Llano series of Texas, and the Algonkian series of the Lake Superior region afford an opportu-

[1] Bull. U. S. Geol. Survey No. 30, 1886, p. 41.

[2] Tenth Ann. Rept. U. S. Geol. Survey (for 1888-89), 1890, p. 66.

[3] Bull. U. S. Geol. Survey No. 86, 1892, p. 493.

nity of comparing the stratigraphic succession of somewhat similar lithologic series of strata, but a definite correlation can not be made until a more reliable factor is obtained than lithologic resemblance of the various formations. It is quite probable that the Grand Canyon series and the Keweenawan series of Lake Superior represent the same time-interval; also that the strata beneath Packsaddle Mountain, in central Texas, are the equivalent of the Chuar terrane of the Grand Canyon; but until palæontologic evidence is secured it may be said that these correlations are little more than possibilities. The Grand Canyon, Llano, and Keweenawan series may be referred to the Algonkian, as that system of rocks includes the strata of sedimentary origin between the Archean complex and the base of the Cambrian; beyond that any correlation on trustworthy data is impossible. Mr. Iddings's examinations of the specimens of eruptive rocks in the Algonkian of the Grand Canyon series show the basal flows of the Unkar terrane to be a true doleritic basalt, and that the dikes and the upper flows, as exposed in Chuar Butte, etc., are basalts differing but little from the basalts of Tertiary age found in Nevada, Utah, and on the plains in the vicinity of the Grand Canyon. This fact prevents any correlation of the lavas with those of other localities, even though basaltic rocks were found to occur in formations referred to the Algonkian. It is evident that until characteristic fossils are found in the various terranes now referred to the Algonkian it will be impossible to make any correlations that will be more than tentative suggestions.

CHARLES D. WALCOTT.

NEW LIGHT ON ISOSTASY.

Facilities for the measurement of gravity by means of the pendulum have been greatly improved in recent years. The apparatus devised by Dr. Mendenhall for the Coast Survey not only affords results of high precision but enables an observer traveling from point to point to make at least one measurement each week. During five months of 1894 Mr. G. R. Putnam, of that survey, occupied twenty-six stations, a greater number than has previously been successfully occupied in North America. The measurements have the further advantage that they are homogeneous, being all made by the same observer with the same apparatus; and as it is understood that the work is to be continued, American geologists and geodesists may confidently look forward to such a knowledge of the distribution of mass in the continent as will materially clarify conceptions of the inner earth.

A brief report of Mr. Putnam's results was communicated by Dr. Mendenhall to the National Academy of Science, and printed in the *American Journal of Science* for January. A fuller account of the work and a discussion of the results were presented to the Philosophical Society of Washington by Mr. Putnam, and have recently appeared in the Bulletin of the Society. Under the same cover also are comments by the present writer.[1] While these discussions are merely tentative, and were undertaken primarily for the purpose of indicating the most advantageous directions for future work by the Coast Survey, certain of the inferences drawn are of such importance and so little liable to be overthrown that their presentation to the readers of the Journal seems warranted.

[1] Results of a Transcontinental Series of Gravity Measurements, by George Rockwell Putnam; and Notes on the Gravity Determinations reported by Mr. G. R. Putnam, by Grove Karl Gilbert. Bull. Phil. Soc. Wash. Vol. XIII., pp. 31–75.

The majority of the stations are arranged in a chain from the eastern coast to Salt Lake City. Two stations are on the Pacific Coast and three in Yellowstone Park. In discussing the measurements, I have started with the general postulate that continents and ocean beds are in isostatic equilibrium, and have sought to determine from the local values of gravity the extent to which various geological provinces of the country deviate from perfect isostatic adjustment. Between the Appalachian and Rocky Mountains is a great plain, which has been exempt for a succession of geologic periods from orogenic disturbances, and during that time has had exceptional opportunity for the gradual relief, through viscous flow, degradation and sedimentation, of the strains engendered by gravity in connection with anomalies of density. It seems, therefore, *a priori* probable that this plain is in approximate equilibrium; and, if so, the average attraction on the plain may advantageously be used as a standard of reference in the consideration of other provinces. Eleven of the stations belong to the plain and they are well spaced from east to west. An examination shows the values of gravity at these stations to be notably accordant. When the mean of the eleven measurements is subtracted from the several measurements, the average residual is found to be only $\frac{1}{120000}$ of g, or such a differential acceleration as would be caused by the addition or subtraction of a layer of rock 240 feet thick.

Referring all the measurements to the standard thus obtained, it is found that there is an excess of attraction in all the mountain districts where measurements were made. In the Rocky Mountains of Colorado there are two stations, at Pike's Peak and Gunnison, and the excess of gravity determined at these stations is equivalent to the attraction of a rock layer 2200 feet thick. That is to say, if this mountain belt, 150 miles broad, were pared away to an average depth of 2200 feet, the local gravitation would then correspond to that on the interior plain. Now it also appears, as a generalization from the Hayden contour map of Colorado, that if this same district were leveled by removing the mountain tops and using the material to fill the valleys, it would

be converted into a plateau between 2000 and 2500 feet higher than the adjacent portion of the plain. The conclusion is thus reached that the whole mountain mass above the level of its base is in excess of the requirement for isostatic adjustment; or, in other words, is sustained by the rigidity of the earth. Three stations in Yellowstone Park tell the same story as to the Rocky Mountains of Montana, and single stations on the Wasatch Plateau and the Appalachian Mountains indicate that those uplands are rigidly upheld.

These results tend to show that the earth is able to bear on its surface greater loads than American geologists, myself included, have been disposed to admit. They indicate that unloading and loading through degradation and deposition cannot be the cause of the continued rising of mountain ridges with reference to adjacent valleys, but that, on the contrary, the rising of mountain ridges, or orogenic corrugation, is directly opposed by gravity and is accomplished by independent forces in spite of gravitational resistance.

While the new data thus indicate that the law of isostasy does not obtain in the case of single ridges of the size of a large mountain range, they agree with all other systems of gravity measurements in declaring the isostasy of the greater features of relief. The mode of reducing gravity measurements at different places so as to make them comparable depends on the theoretic conception of terrestrial rigidity, one method being followed when high rigidity is postulated and another when isostasy is postulated. Under the postulate of high rigidity it is assumed that all parts of the crust have the same density; under the postulate of isostasy each vertical element of the crust is assumed to have the same mass, density being inversely related to altitude of the surface. If either of these postulates were absolutely true the measurements, when reduced in accordance with it, would become identical, except for errors of observation; and approximation to such identity is a measure of the degree of approximation of the corresponding postulate to the actual fact. Mr. Putnam and the writer independently applied

this test by reducing series of measurements under each of the two postulates, and our conclusions are of the same tenor. Treating fourteen measurements, he found the results obtained under the postulate of rigidity fifteen times as discordant as the results under the postulate of isostasy; treating twenty-six measurements, I found the ratio as six to one. These measurements pertain to stations distributed among the plateaus that make up the continent, plateaus ranging in general attitude from 100 feet to 8700 feet; and the comparison shows that these plateaus are approximately in isostatic equilibrium.

G. K. Gilbert.

STUDIES FOR STUDENTS.

JAMES D. DANA AS A TEACHER OF GEOLOGY.

To sit at the feet of Professor Dana and drink from the overflowing fountains of his knowledge, was a privilege which once enjoyed could never be forgotten. One knew not which to admire most, the simplicity and nobility of his character, or the breadth and grasp of his intellect. Yet none could fail to be impressed with the fact that one was the complement of the other. Had he been less keen, thoughtful, impartial, he would have been less admirable as a man. Had he been less sincere, unselfish, truth loving, he would have accomplished less as a scientist.

Unconsciously but irresistibly as he taught geology, he revealed to his students his own character, and all which he revealed made them long to know him more deeply and truly. He imparted to them too, unconsciously I have no doubt, the principles of the successful pursuit of knowledge and the methods by which progress in science is attained which had enabled him to accomplish Herculean tasks in the same direction and to occupy the prominent place which he did among the scientific workers of his time.

Glancing over the notes of his talks which I made during the two years that I was privileged to study under his instruction, I find many aphorisms which he let fall indicating the methods by which his own success in scientific work was attained. Thus, when stating the different theories which had been proposed regarding the mode of formation of coral islands, he expressed a wish that borings might be made so as to learn on what foundations the islands rest, remarking, "When I get at a thing I want to go to the bottom of it and then I am willing to leave

it." The remark reminds one much of the answer given by Lincoln to a question as to how he gained so clear a knowledge of the subjects with which he dealt, when he said: "I cannot rest easy when I am handling a thought till I have bounded it upon the north, upon the south, upon the east and upon the west."

Another maxim which it would be well to keep in mind in these days of easy publication Professor Dana gave utterance to when, in referring to some of the theories which were being advanced at the time to account for the subsidences of the earth's crust, he said: "I think it better to doubt until you know. Too many people assert and then let others doubt."

The same judicial poise was exhibited in his readiness to change his former opinions when he became convinced that the evidence was sufficient to warrant it. Absolute candor and desire to support only the truth as he saw the truth were among his principal characteristics, and he sought constantly to impress upon his students their importance as factors of success in the pursuit of knowledge.

Thus in studying the Cambrian era, which the labors of Walcott and others at that time had shown to be of far greater extent and importance than had previously been supposed, his students were told to regard it as of equal importance with the Lower Silurian, though in his text-book it was one of the subdivisions of the latter, and his remark at the time was: "I have found it best to be always afloat in regard to opinions on geology."

So too in accepting as divisions of independent continental progress, the Eastern Border, Eastern Continental, Interior Continental, Western Continental and Western Border regions, a classification which differed from that which he had previously made, he said: "I always like to change when I can make a change for the better."

In adopting views which had been originated by others, he never sought to assume from them any credit to himself, but freely gave honor to whom honor was due. This was well illustrated in his espousal of Darwin's theory of the formation of

coral islands. It was a subject to which before the publication of Darwin's views he had himself given much thought, without arriving in his own mind at any satisfactory hypothesis. "As soon as Darwin published his theory, however," said he, "I saw at once that it solved the difficulties of the case," and though he did much to expand and verify it, he never claimed it in any degree as his own. His change of opinion regarding the theory of evolution is likewise well known, and he never hesitated to mention it in his lectures upon the subject.

Upon those, however, who sought to gain scientific repute by any other means than a careful and unbiased study of facts, his strictures were severe. One geologist of some prominence he described as "a man of wonderful resources, because he had only to go to his own brain for facts," and his students were often warned against accepting any of such an observer's conclusions

Woe likewise to the student who sought to conceal the bubble of his ignorance with a thin varnish of words. The bubble would be pricked with a celerity and suddenness that left no desire for a repetition of the experiment.

No man, however, was ever more ready, even eager, to assist those who wanted to obtain knowledge. While he had no time to waste on those who studied geology only as a matter of form, his resources were freely at the disposal of any who displayed intelligent interest in the subject.

One way in which he evinced this was by the long walks which he was wont to take with his students about New Haven, or other trips to places more distant. Though these were over the same ground year after year, he never seemed to weary of the journey so long as his students showed any desire to be instructed by what they saw. Even to the very last of his life these trips were continued, the teacher of nearly fourscore years traveling over rocky steeps and through brambly thickets with all the ease and sprightliness of youth and at a pace which his younger followers found difficult to imitate. The number and variety of illustrations of geological principles which he could point out in such walks of a few hours were indeed remarkable,

and taught his students that they need not go to distant parts of the earth to make geological observations, for they could find material sufficient for study at their own door. The trap ridges, kettle holes and bowlder trains of the vicinity of New Haven have thus become of classic interest, not because they presented any unusual features, but because Professor Dana resided near them, studied them, and gave to the world the results of his observations.

No operation that was carried on within the range of his observation, the details of which could add to the sum of geological knowledge or help solve any of its problems, seemed to escape his notice. Every railroad cut, every survey, every excavation and every boring he carefully watched and gained from them facts which helped him interpret the past history of the earth.

The bricks which were burned in the Quinnipiac kilns he had analyzed in order to learn why they fused so easily, and gained thereby important information regarding the source of the clay. By the dolomitic blocks of the State House he illustrated to his classes the principles of the disintegration of limestone, and by the granite pillars of the Peabody Museum the expansion of stone by heat. From watching the drying of a drop of milk on a stone floor he derived an explanation of the forms produced by concretionary consolidation, and by experimenting with varieties of sand dropped about an upright darning needle established the principles governing the angle of rest for falling detritus.

His ability to retain in his mind various phases of geological evidence, and develop them as time progressed, was likewise remarkable. Thus, in 1889, in his teaching he laid much more stress on the influence of the Cincinnati uplift in determining the character of the rocks of the interior of the continent than he had previously done in his Manual, for he said he had never so fully realized its importance as he had that year.

Nor were his students compelled to receive obsolete theories or time-worn illustrations because he had held or used them

in the past. On the contrary they were kept informed of the newest discoveries and latest phases of geological thought and urged to judge for themselves of their importance and bearing upon previously attested principles. With all the varied lines of thought and discovery he kept in closest touch, and seemed equally appreciative of their value, whether they related to the eruptions of Kilauea, the Algonkian formation, Mesozoic mammals, the causes of oscillation of the earth's surface, or what not. Of this progressiveness and appreciation of all additions to the sum of geological knowledge his newly published Manual gives sufficient evidence.

The quality in an investigator which, other things being equal, he seemed to esteem most highly, was that of *carefulness*. How often were his students advised to trust or to doubt the statements of an author according as he was or was not, in the opinion of Professor Dana a *careful* man. With hasty and ill-considered conclusions or elaborate theories built from meager observations he had no patience, but to opinions which he believed had been derived from a careful and thorough study of facts, he was ever ready to give the fullest consideration, however much they might be opposed to his previous conclusions. "More," he said, "could be learned by studying unconformities than conformities," and this he believed to be as true of unconformable opinions as of heterogeneous strata.

The awakening in his mind of the interest in science which became the ruling passion of his life, and led to his signal achievements for its advance, Professor Dana used to ascribe largely to two causes, one that of having spent much of his early life in the country, the other, his first teacher. In connection with the first he used to deplore the lack of development of the faculties of observation and the ignorance of nature consequent upon life in the city and placed a high estimate upon the education unconsciously gained by an association with the beings and phenomena of the natural world. As an illustration of this the author recalls an occasion when having passed in vain nearly around the class for a statement of the differences between a moss and a phenog-

amous plant, Professor Dana turned to one of the few remaining who had not confessed their ignorance, with the remark, "You are from the country, you ought to know." And he did.

Professor Dana's first teacher was an ardent student of nature who was wont to go with his pupils on long tramps for the purpose of collecting minerals, plants and insects, and aroused in them much of his own eagerness for the pursuit of knowledge. It is therefore but just that some of the fame of his distinguished pupil should be attributed to him. One incident which Professor Dana used to relate to illustrate his teacher's fervor as a collector was that when on one occasion his little party had gathered at a remote place more mineral specimens than they could carry in their hands, the master, in preference to leaving any behind, improvised a bag from a pair of trousers and thus bore them safely to their destination.

To rehearse at this time the principles of geology which Professor Dana taught, or to state the opinions which he gave to his classes upon mooted geological questions of the day, would be quite superfluous, since they have been sufficiently expressed in his recently published Manual, a work fortunately completed just before his death and which came, as another has said, as "the worthy consummation of a long life of exceptional earnestness and success as author, investigator, editor and teacher."

But lest, in contemplating the splendor of his principal achievements, the sidelights which revealed the man and his methods should pass unheeded, it has seemed to me desirable to fix and record them for the encouragement and guidance of those who may desire, however humbly, to follow in his footsteps. There can be no doubt that with him the tenth muse was work, in whose wake the other nine followed, yet the union to this capacity for almost unlimited labor, of breadth of mental vision, calmness of judgment, fertility of resources, strict integrity and loftiness of purpose, did much to render it effective, and enable him to accomplish more than perhaps any other man of his time for the advancement of American geology.

OLIVER C. FARRINGTON.

EDITORIAL.

In the death of Professor James D. Dana, American geology loses its most eminent representative. With due recognition of the preëminence of others in their chosen lines, no one has stood before the scientific world for the last three decades so widely recognized as the foremost general geologist of our hemisphere as Professor Dana. The period of his activity has stretched over a full half century. From the time of the publication of his great work on the results of the Wilkes Exploring Expedition, his eminent ability has been recognized, and the appearance of his manuals of geology and mineralogy, which soon followed this, gave him a position of unequaled influence among the teachers and students of those sciences in this country. Upon these works his reputation chiefly rests. Owing to the delicacy of his health his field work was limited, and subsequent to the Wilkes Expedition, which gave him so comprehensive a familiarity with the great features of the earth, his personal field investigations were chiefly confined to the region adjacent to his home. His main work was that of compilation, interpretation and organization, and in this delicate field he showed great judgment and discretion. As we hope to publish a full and appropriate memoir at an early date, and as we give in this number a sketch of his characteristics as a teacher, prepared by an admiring pupil, it would be unfitting here to attempt a full analysis of his conspicuous services or his abilities. He preserved his activity to the end of his life, fourscore years and ten and two, in a remarkable degree. The revision of his Manual of Geology, but just issued from the press, is a conspicuous illustration of this. But his activity did not rest even here, as it might very fittingly have done after so arduous a task. In a

letter to Mr. Leverett, only two days before his death, he added to the immediate purpose of his communication a discussion of the mode of deposition of the loess. By permission this is here added because of its interest as one of the latest, possibly indeed the very last, scientific discussion which he committed to writing. C.

[*Extract from a letter written by Professor James D. Dana to Mr. Frank Leverett, dated April 12, 1895, but two days before his death.*]

"With regard to the eolian work along valley plains, I think great caution is necessary because eolian work is of a fitful kind. The more powerful winds blow in gusts, or rather a succession of them, and each of the gusts is of rather narrow limit; and in each gust great velocity is succeeded by a decline in which the depositions vary accordingly as to coarse and fine and limit. Making loess — unstratified — by the winds would require a steady breeze sufficient to move the light earth or sand long in a common direction, but too near unvarying in force or velocity to produce alternations from coarse to fine. It is an even kind of work that winds are not often fit for. They heap up at the slightest provocation, strike the ground and glance off when of greatest force. It takes something of a breeze to even start the dust of a road, because the dust is 2000 times heavier than the air and the air near the ground slips over the surface readily without disturbing it. Excuse me for thus discoursing on wind work.

"Do you know what is the size of the largest pebbles taken up by a storm wind from a level surface and carried, as it carries sand, for a few yards? The houses in the track of some of the great western gales must have windows sometimes broken in this way; and perhaps their owners, if reliable, could give some facts worth knowing."

***

An additional loss has been suffered by geology in the recent passing of Professor Henry B. Nason. While primarily a chemist and mineralogist, Professor Nason was an earnest and conscientious student and teacher of geological phenomena. An exceptionally wide traveler, his personal familiarity with American and foreign deposits was unusually extensive, and gave to his instruction breadth and balance. His primary geological interest lay in the field of volcanic phenomena. Although an

author and an editor of chemical and mineralogical works, his great modesty withheld him from publication in geological lines, so that it was chiefly as a teacher that his wide observations were made serviceable. The writer owes to Professor Nason, as his first teacher in geology, a debt of gratitude for the initial awakening of what has become the dominant interest of his life. Professor Nason was one of the founders of the American Geological Society. C.

PUBLICATIONS.

Die Entstehung der Blei-, Zink- und Eisenerzlagerstätten in Oberschlesien. Eine Besprechung von H. Höfer. Separatabdruck aus der "Oesterreichischen Zeitschrift für Berg- und Hüttenwesen." XLI. Jahrgang, 1893.

This very interesting paper is itself a review of three publications by Küntzel, Fr. Bernhardi and Rich. Althans, which were presented at the Breslau meeting of the Verein der Allegemeinen Deutschen Bergmanstage, all treating of the ore deposits of Upper Silesia.

These important deposits, from which have been derived by far the greater part of Germany's zinc output, are briefly and excellently described by Althans, as follows:

"The ores of the Upper Silesian Muschelkalk[1] are principally galena, zinc-blende, smithsonite, marcasite and limonite. These occur in bed-like deposits in the dolomite of the Lower Muschelkalk, the beds being usually more or less connected. Generally two beds, or deposits at two different horizons, can be distinguished: one immediately above what is known as the Sohlenstein and separated from it only by a bed of slate known as Vitriolletten, or by a layer of dolomite which is seldom over one or two meters thick; the other in the mass of the dolomite at a very variable distance above the first. The upper one is of much more irregular distribution than the lower; in the Trockenberg basin it is indeed almost entirely absent. Both are in part purely lead-bearing, but they are then rarely more than a meter thick, and at the same time are much interrupted; in part they are predominantly zinc-bearing, and in this case they are much thicker and occur more frequently as continuous beds. The lead-bearing beds belong principally to the Trockenberg basin, the zinc-bearing almost exclusively to Beuthen. In both, the whole thickness is not of compact ore, but this is almost always intermixed with dolomite, which, in fact, generally makes up the mass of the ore body. Where the deposits are zinc-bearing, the lower portion consists mostly of zinc-

[1] Lower Triassic.

blende, together with sulphide of iron and galena; the upper part consists almost exclusively of the so-called red calamine, that is, a ferruginous, zinciferous dolomite, with some galena. The dolomite, which occurs both below and above as well as *in* the lower blende-bearing beds, has almost always the original bluish gray color, whereas in proximity to the upper portion it is more or less decomposed.

"Towards the outcrop the deposits of the two principal horizons unite and form a body that in places is as much as twenty meters thick. Here it consists principally of the red calamine with galena. The ore often extends also down into the Sohlenstein, along crevices and pipes, in which case it is more clayey. In the extremities of these openings the iron contents also disappear, so that the ore passes into a white calamine (a dolomite rich in $ZnCo_3$)."

The three publications referred to include maps and descriptions of the ore deposits, and discussions of their genesis. Höfer considers principally the last, analyzing and comparing the different hypotheses in a very interesting manner.

Thus, Bernhardi maintains the hypothesis that, after the deposition of the basal Sohlenstein formations, rich solutions of zinc, lead and iron salts were introduced into the Triassic sea, from which they were precipitated either by CO_2 or H_2S, which were evolved in abundance from the then recently formed and underlying coal beds. The ore deposition was most abundant where these gases were generated in greatest quantities.

Bernhardi bases his conclusions upon the fact that the zinc deposits are developed in the Muschelkalk only where there are well-developed coal formations beneath, and especially where such outcropped in the floor of the Triassic sea. Höfer calls attention to the deposits of Tarnowitz as an exception, and remarks, very truly, that this condition is equally favorable to the hypothesis of infiltration as to that of original deposition.

In further support, Bernhardi cites the facts that there are no evidences in the underlying Coal Measures or in the Sohlenstein that the ores have come from below, and, further, that faults of the Coal Measures either do not extend into the Muschelkalk or have very little throw there. These facts Höfer classes also as equally favoring infiltration.

Against the latter hypothesis Bernhardi instances the stratum like form of the ore deposit, and the unaltered or unoxidized condition of the dolomite which is associated with the sulphides. Höfer does not

think these objections valid. The stratified form, he argues, might readily be due to the impermeability of the Sohlenstein, which would cause the waters to flow along the contact between it and the permeable dolomite above, while the carbonaceous Vitriolletten bed would precipitate the ores. The unoxidized condition of the dolomites and clays does not mean necessarily that no waters traversed them, but merely that these waters had no air or free acids in solution. Such could well have been exhausted, says Höfer, in oxidizing the sulphides of the higher strata, before transporting them to the present ore horizons. Further, Höfer reasons, on the hypothesis of sedimentation, beds of dolomite and limestone would have been deposited in alternate layers in the ore body, as they were before and after. Not only is this not the case, but Bernhardi describes a brecciated structure which sometimes characterizes the greater part of the deposit, where blocks of dolomite are cemented by the ore. This condition, as well as the presence of vertical and other ore-bearing crevices in the dolomite, is incompatible with a sedimentary origin of the ores. Hence, Höfer thinks, this hypothesis must be abandoned.

Althans, in discussing the source of the ores, shows that Krug von Nidda's explanation, that the solutions came from below through pipes or chimneys, will not hold, because when such pipes have been followed into the Sohlenstein they have always come to an end.

Against Dr. Kostmann's hypothesis, that the solutions came from the interior through crevices or fissures, are the facts that the fissures of the Coal Measures almost never extend into the Triassic; that there are no deposits in the underlying bituminous Sohlenstein, and that no such source of supply has been encountered or is indicated in mining operations. Höfer, therefore, discards also the hypothesis of ascending solutions.

The remaining alternatives are defined as follows:

1. The metals were originally diffused in the sedimentary complex overlying the Sohlenstein and subsequently leached out and deposited at the present ore horizon.

2. The ore deposits were originally concentrated sediments which acquired their present forms by subsequent rearrangements and changes.

The first of these hypotheses was advanced long ago by Carnall, and was accepted by Websky, Runge, Römer and others. These older authors referred to the dolomite alone as the source of the ore, and

Carnall estimates that 0.0008 per cent. of galena in this rock would suffice to supply the ore deposits. Such a minute quantity, it is argued, might well escape detection in the analysis of limestone; but, Höfer remarks, even the absence of the metals in the dolomites at present is no objection, since they have been already leached out. Althans thinks it highly probable that not only the dolomite but also the Upper Muschelkalk and Keuper beds, and even others lying higher contain diffused metals and were sources of supply to the ore deposits. But Höfer thinks this improbable because of impervious beds in the Keuper and also at the base of the Upper Muschelkalk.

In conclusion, Höfer sees no unanswerable objection to the explanation of the origin of the ores by descension and infiltration.

The second alternative hypothesis was advanced by an anonymous G. W. in 1883. It resembles somewhat Chamberlin's hypothesis applied to the Wisconsin ores, though the causes and conditions of original concentration are somewhat different and the degree of concentration somewhat greater than Chamberlin requires.

Höfer evidently favors this explanation, without distinctly saying so, but confines himself to the conservative statement that it deserves more consideration. Against Althan's objection that such enormous metalliferous deposits could not be precipitated directly from sea water, he refers to the iron deposits of the southern shore of the Oberen Sea and to the Rammelsberg copper deposits. The sea water of past ages can well have had, he argues, higher metalliferous contents, seeing that so much has now been extracted to form our ore bodies. The abundance of carbonaceous matter at the beginning of the dolomite formation would cause an excessive if not entire precipitation of the metal contents of the sea water. As the bituminous Vitriolletten became covered this would diminish. The dolomite being throughout somewhat bituminous a constant separation of metals in small quantities probably continued, sufficient to impregnate the rock and to account for the scattered occurrences of ore found in it. The alteration of the original deposits to their present forms must have taken place later, after oxidizing influences began to act. Höfer considers this hypothesis simpler, in that it does away with the necessity for the transportation by infiltration of metalliferous salts, and the whole open question of their solubilities is eliminated.

After briefly reviewing similar ore deposits of other parts of Europe, our author concludes that they cannot be better explained than on the

hypothesis that the strata were ore-bearing at the time of their formation, and that the metals were derived from sea water.

This paper is well worthy of study by American geologists. Whether the explanations are applicable to any of the similar ore deposits of this country or not, the discussions are full of suggestion, and are instructive examples of conservative reasoning.

ARTHUR WINSLOW.

ST. LOUIS, March 13, 1895.

Fragments of Earth Lore. By JAMES GEIKIE, D.C.L., LL.D., F.R.S., *etc.* 428 pp, 6 plates. John Bartholomew & Co., Edinburgh.

This volume contains a series of essays and addresses, most of which have been published elsewhere. Many of them have appeared in the Scottish Geological Magazine, while some have appeared in other publications which are less accessible to American readers. The scope of the volume is indicated by the following titles which serve as the headings of as many chapters: Geology and Geography; The Physical Features of Scotland; Mountains, their Origin, Growth, and Decay; The Cheviot Hills; The Long Island, or outer Hebrides; The Ice Age in Europe and North America; The Intercrossing of Erratics in Glacial Deposits; Recent Researches in the Glacial Geology of the Continent; Glacial Period and the Earth-movement Hypothesis; The Glacial Succession in Europe; The Geographical Evolution of Europe; The Evolution of Climate; The Scientific Results of Dr. Nansen's Expedition; The Geographical Development of Coast Lines.

As will be seen by the titles, the several chapters have no intimate relation to each other, though most of them deal with geographic phases of geology. Each chapter is complete in itself. While some of the essays deal with phenomena which are local, all of them deal with principles which are more or less general in their nature, and many of them deal with phenomena which are of universal interest. The subjects are treated in a way which is popular without being unscientific. A service is rendered to students and teachers of geology in collecting and presenting the essays in a single volume, which should find a place in every geological and geographical library. The untechnical language of the essays will make the book available for

the use of many who are not specialists in the sciences to which the essays especially relate. The maps are very valuable, but the volume is otherwise but slightly illustrated.

R. D. S.

Post-Glacial Submergence in the Region of the Great Lakes.

Raised Beaches of Lake Michigan. Frank Leverett. (1889) Wisconsin Academy of Science, Vol. VII., 83–87.

Abandoned Shore-lines of Green Bay. By F. B. Taylor. American Geologist, Vol. XIII., May, 1894.

Abandoned Shore-lines of the South Coast of Lake Superior. By F. B. Taylor. American Geologist, Vol. XIII., June, 1894.

Coastal Topography of the North Side of Lake Superior. By A. C. Lawson. (1893) Twentieth Annual Report of the Geological and Natural History Survey of Minnesota for 1891, pp. 181–289.

Ancient Strait at Nipissing. By F. B. Taylor. Bulletin Geological Society of America, Vol. V., 1893.

Limit of Post-Glacial Submergence in the Highlands East of Georgian Bay. By F. B. Taylor. American Geologist, Vol. XIV., November, 1894.

The Duration of Niagara Falls. By J. W. Spencer. American Journal of Science, 3d Ser., Vol. 48, p. 455, December, 1894.

The investigations by various observers within the last five or six years have added greatly to our knowledge of the Pleistocene history of the Great Lake region. Following is a brief summary of the results of these observations.[1] Mr. Leverett's paper deals with the raised beaches and sea cliffs around the head of Lake Michigan. Three distinct beaches are recognized which are continuous and traceable for a long distance. These are designated the Upper, Middle and Lower raised beaches. Between Waukegan and Winnetka, Illinois, the lake is farther west than when the beaches were formed and is gradually encroaching upon the till-covered country beyond. At Winnetka the base of a sea cliff twenty feet high lies sixty feet above the level of Lake Michigan (641). Southward the cliff becomes continuous with the

[1] For convenience the elevations referring to sea level are placed in parenthesis.

upper beach of gravel and sand which maintains an altitude of sixty feet to within a short distance of the Chicago River where it decreases to a height of forty feet (621). At La Grange there is another sea cliff with its base forty-six feet above the lake. At the time this beach was formed, the lake had an outlet down the Des Plaines valley at Summit, and another entered the same valley from the east at The Sag, about three miles below. The depth of water passing through this outlet at the time this higher beach was formed was forty or fifty feet. East from Summit, the beach ridge stands at sixty-five feet near Homewood (646), fifty-five feet near Glenwood, and eastward to Dyer, in Indiana (636).

The middle beach is about twenty-five feet below the upper, and the lower beach ten feet below this.

Beginning at Sheboygan, Wisconsin, Mr. Taylor's observations extend northward along the western shore of Lake Michigan. The greatest submergence noted is not considered by this author to be represented by any of the terraces described by Mr. Leverett. Evidence of submergence was found at Kewaunee in a low terrace fifteen to twenty feet above the lake (601). Northward the corresponding beach lines rise gradually, and at Menominee on the west coast of Green Bay, there is a well marked beach ridge fifty feet above the lake (631). On the north shore of Green Bay several beaches are distinguished, the highest being 135 feet above the lake (716). Northward from Brampton the general appearance of submergence seemed to extend some distance north of Lothrop, which is 460 feet above the lake (1041), but no shore line was seen. At Marquette a strongly developed shore was found at 590 feet above Lake Superior or 1191 feet above sea level. There is thus seen to be a depression in the beach lines in the vicinity of Kewaunee, north of which the rise is about eight inches per mile for seventy-three miles, while the succeeding sixty-three miles have a rise of from two feet two inches to two feet four inches per mile. Compared with the eastern shore of the lake, the beach on the west appears to be about twenty to thirty feet lower in the same latitude.

Along the south shore of Lake Superior the line of submergence ranges from 572 feet above Lake Superior at Duluth (1173) to 630 feet at Marquette (1231), decreasing from this point eastward to 452 feet at Sault Ste. Marie (1053) (Lawson). The suggestion is made that during the great submergence the Superior basin connected with Hudson Bay by one or more straits.

According to Lawson a very evident relationship exists between the topography of the north side of Lake Superior and the geological structure of the region. From Duluth eastward the Keweenian, Animikie and Archean constitute successive geological provinces marked by characteristic topography. The Potsdam is represented to a limited extent in the vicinity of Sault Ste. Marie, and is of especial interest as forming the dam in St. Mary's River which holds the waters of the lake at their present level. The beaches, bars, spits, deltas and wave-built terraces are described in detail. The highest mark of submergence was found at Mt. Josephine at a height of 607 feet above the lake (1208), while the number of strands recognized in at least two localities was thirty-one, ranging up to a height of 534 feet (1135). This was the level of the highest strand noted at Duluth, while at Sault Ste. Marie the highest was 413 feet (1014). It is evident, however, that owing to the difficulties attending observation the record of the higher strands is very incomplete. On the supposition of the lowering of a lake barrier to the southeast it is evident that the outlet of the vast sheet of water represented by these strands shifted from time to time in consequence of continental warping. The evidence of an outlet into Hudson Bay referred to by Taylor is given and others noted.

Observations at Mackinaw Island had shown the existence of a shore line 205 feet above the lake (786) which was correlated with the Algonquin beach of Spencer, and the belief was entertained that an old outlet of Lake Warren would be found at Nipissing. Later investigation, the details of which are given in the fifth paper, corroborated this conclusion. This ancient strait, as defined by the two highest shore lines, was about thirty-two miles wide where observed, narrowing eastward to about twenty-five miles. Its depth over the low pass between Lake Nipissing and Trout Lake must have been nearly 500 feet.

The last paper by Mr. Taylor records the results of observations between Lakes Simcoe and Nipissing, where the altitudes of the highest beaches observed range from 780 feet above sea level at Barrie to 1140 at North Bay on the east shore of the latter lake. The identity of the upper beach of the Nipissing region with the Iroquois or Algonquin beach of the Ontario basin is reaffirmed.

The eastward rise of the Algonquin beach noted by Dr. Spencer in the region west of Lake Simcoe was corroborated. Great silt-beds were found showing singular alternations of clay and silt in laminæ often not more than one-half inch in thickness. The evidence is con-

sidered strongly against the theory of glacial dams, and favors the inference that the submergence was an invasion of the sea through a strait over Lake Nipissing.

Previous estimates of the age of Niagara Falls are given in the paper by Dr. Spencer, and attention is called to the error introduced into the later computations by neglecting to take into account the changing episodes of the river. It is noted that previous writers have overlooked the presence of an ancient drainage of Lake Erie about forty miles west of the Niagara. Moreover, the assumption often made that the old course of this river passed through the whirlpool ravine is shown to be erroneous.

There was no preglacial Niagara River, and the present channel has been cut almost entirely in limestone. The Horseshoe falls during forty-eight years has shown a mean rate of recession of 4.175 feet per year. The American falls, however, has retreated but 0.64 feet per year during this period. Four different episodes are recognized. The first represents the recession of the falls from the escarpment to the level of the Iroquois beach, which is computed to have occupied 17,200 years. The second stage began with the lowering of the water at the end of the first and the recession of the falls to the vicinity of the whirlpool—a period of about 10,000 years it is thought. The third stage was the time passed at the whirlpool rapids—computed to be 800 years. The fourth episode is characterized by the rising of the waters in the Ontario basin. In the first part of this episode the river cut its way through a ridge (Johnson's) of limestones, following which comes the modern stage of the falls. The duration of this epoch is placed at 3000 years, making a total of 31,000 years, or, allowing 1000 years for the time before the advent of the falls, the age of the river is 32,000 years.

In the deformatory elevation of the district, Johnson's ridge was raised twenty-four feet above the Chicago divide, causing an overflow in this direction which threatened to end the falls when the cut through the ridge was effected. On this basis the drainage of Lake Michigan by way of the Des Plaines ended about 1500 years ago. At the present rate of terrestrial deformation, the falls will come to an end in about 5000 years, by the turning of the waters into the Mississippi. The conclusions of the paper are based on a long series of observations which have been given in detail in a number of papers, a list of which accompanies the present article. C. H. G.

Geological Survey of Ohio ; Geology, Vol. VII., by Professor Edward Orton, State Geologist, 1893.

This volume although entitled "Geology" is of a more or less composite character. It is divided into two parts, the first treating of Economic Geology, and the second treating of the Archæology, Botany and Palæontology of the State of Ohio. These various subjects are treated by various authors. Part I. of the volume is divided into four chapters : Chapter I. on the Geological Scale and Geological Structure of Ohio ; Chapter II. on the Clays of Ohio, their Origin, Composition and Varieties ; Chapter III. on the Clay Working Industries of Ohio ; and Chapter IV. on the Coal Fields of Ohio.

Chapter I., by Professor Orton, gives a general summary of the various geological formations comprised in the state, with special reference to those carrying products of economic value. The Geological structure of the state is also briefly but clearly described, including the Cincinnati axis, the Appalachian folds, and various other structural features of the state.

Chapter II., by Professor Orton, discusses the origin, composition, and nature of clays in general, and describes the different kinds found in Ohio. The lowest formation in the state known to have been worked for clay is the Medina shale in the Upper Silurian, and from this up to the Coal Measures numerous other formations contain clays of commercial value. The most important deposits are in the Carboniferous rocks, and especially in the coal mining districts where they are often directly associated with coal. By far the most extensively used deposit in the state is what is known as the Kittanning clay in the Carboniferous series.

Chapter III., by Edward Orton, Jr., is a very exhaustive and an exceedingly valuable article on the clay industries of Ohio. He shows that the manufacture of clay wares in Ohio has increased immensely in the last ten years, so that it is now second only to coal mining among the industries developing the natural resources of the state. The nature and origin of clays and their chemical and physical properties as related to their commercial uses, and the methods of testing them, are treated in detail. The present prosperous condition of the clay industry of the state is shown to be dependent largely upon the manufacture of pottery, paving materials, pipes, refractory materials and building materials. Each one of these classes of

materials, and their manufacture in Ohio, is then discussed. The newest of these industries, and the one which has shown the most marked increase, is the manufacture of paving materials which, in the form of vitrified bricks, have been shown to have remarkable endurance even under heavy traffic. The industry has increased at a wonderful rate during the past five years.

This article presents the subject in a clear and concise manner. It shows a thorough insight into the clay industry and is sure to be of much value to those interested in the development of clay deposits, not only in Ohio but elsewhere.

Chapter IV., by Professor Edward Orton, is a thorough discussion of the coal resources of the state, and a résumé of the work which has been done by the survey in previous years in this field. The author first discusses the origin of coal in general, and shows the gradual development of the peat theory from the time it was originally suggested by Leo Lesquereux until the present. The Ohio coal is shown to have been formed in long narrow belts following the line of an old bay of the Carboniferous ocean, which had for its western limit and shore line the gradually rising Cincinnati axis. The coal, therefore, is to be expected to occur on lines running parallel to this old shore and gradually to disappear in the other direction, *i. e.*, at right angles to the shore.

The coal-bearing rocks underlie 10,000 square miles in eastern Ohio, but coal does not occur throughout all of this area. There are fifteen or eighteen seams of coal of economic value, ten of which are of much importance. In the series of rocks carrying the coal, there are twelve beds of limestone, some of marine and some of brackish water origin, which are often more or less replaced by iron.

The value of coal and the wasteful methods of mining and using it, practiced in Ohio and elsewhere, are severely criticised. It is shown that Ohio has probably, according to two different calculations, 12,000,000,000 and 20,000,000,000 tons respectively of available coal left, and that if the rate of consumption should advance as it has done in recent years until it reached a maximum of 100,000,000 tons yearly, the coal of the state would last, according to two different calculations only one hundred and two hundred years, respectively, while if the rate of increase ceased at 25,000,000 tons yearly, the coal would last five hundred and eight hundred years respectively,

The nature and distribution of the different coal seams are dis-

cussed in full, and the volume is accompanied with ten maps, one showing the general distribution of coal in the state and the other nine showing its distribution over local areas. These maps outline the course of the outcrops of the coal and the probable area underlaid by different seams, so that they will be of very great value to all those interested in the present or prospective development of coal fields. Probably no one feature developed by the Ohio Survey in its many years of existence will be of more economic value than these maps.

The important oil and gas resources of the state are not treated in full, but are briefly discussed in the preface. The most important recent developments in the oil industry are the increased number of discoveries in the Trenton limestone, and the increased production from that source. This formation is now the leading source of illuminating oil in the United States.

The supply of natural gas has greatly decreased in the last few years. In 1890 Professor Orton made the prediction that unless the reckless waste of gas was restrained, the supply would soon be exhausted. At that time the use of gas was at its height and was adding immensely to the welfare of the state, not only in supplying a cheap, clean and convenient fuel to the people of the state, but in attracting new manufacturing industries. The predictions of Professor Orton, therefore, were criticised as entirely unwarranted; but recent developments have verified the justice of his warnings. Most of the gas wells show signs of diminished capacity; many have been completely exhausted, and various industries started, or for some years run on gas, have now had to resort to coal.

The chapter on the Archæology of Ohio is by Mr. Gerard Fowke of the Ethnological Bureau of the Smithsonian Institution. It treats the subject in much detail, under the headings of Palæozoic Man; Enclosures, Roadways and Mounds; The Mound Builders; Indians; Relics.

The chapter on botany, by Professor W. A. Kellerman and W. C. Werner, is a complete list of Ohio plants. It combines not only the information given in previous lists, but also many new determinations, making it much more complete than any other previously published and of especial value to those interested in Ohio botany.

Professor Orton states in the preface of the volume that it is the last official publication of the kind that he expects to prepare. This news will be received with much regret by all geologists, and especially by those who have watched Professor Orton's excellent work carried

on in the face of many disadvantages, not the least among which were small appropriations, ever since he assumed control of the Ohio Geological Survey in 1884. A comparison of the state of knowledge on Ohio geology at that time and at the present speaks for itself as to the efficiency of the work he has carried on. In previous years, under the direction of Professor Newberry, many of the most important features of the geology of the state were made known, but many were left undisclosed, and it is to Professor Orton that we owe our knowledge of these, as well as the systematic presentation of many former discoveries. Not only has Professor Orton brought out many facts of very great geological importance, but he has also developed the economic side of the question in an admirable manner, thus rendering the survey useful not only to the scientist, but also to the vast mass of the citizens of the state for whose good the appropriations for a geological survey were especially intended. The collection of purely scientific data in a region is necessarily the first step in the work of a geological survey, and is of great value to all geologists; but he who stops his work here does not fulfill the objects for which appropriations for geological surveys are usually made. The average citizen is not a geologist; purely geological discussions are unintelligible to him. He can draw no deductions from them, and the duty of one in charge of a geological survey is to draw economic deductions from his scientific studies, and publish them in a form which can be understood by the mass of the people of the community taxed to carry on such work. Many who have charge of surveys fail to do this, either because they do not realize its importance, or because they have a weak-minded idea that to make economic publications is unworthy of them.

Professor Orton has in an admirable way given to the people of Ohio all the economic results possible. He has in his various publications first presented his purely geological data, and has then discussed in detail all conclusions therefrom which could be of material benefit to the people of the state. He has thus accomplished the highest objects of a geological survey, and the thanks of the people of Ohio and of the country at large are due him. Most prominent among his works on the economic resources of the state are the treatises on petroleum and natural gas, embodied in Preliminary Reports of Progress, 1886; Vol. VI., 1888, and First Annual Report, 1890. These publications have made him an authority on the subjects

discussed, and have materially assisted in the development of oil and gas resources, not only in Ohio but elsewhere. His other publications on the clays, coal, and other resources of the state are no less valuable, and it may be safely said that no state geological survey has ever been of more advantage to the people of the state than the Geological Survey of Ohio under Professor Orton.

R. A. F. Penrose, Jr.

Geological Survey of Ohio, Vol. VII., *Palæontology*.

A valuable addition to the palæontology of the state of Ohio is included in this volume. Professor R. P. Whitfield publishes in chapter III. a series of papers on the faunas of the Lower and Upper Helderberg, the Marcellus shales, the Huron and Erie series, the Maxwell limestone (equivalents of the St. Louis and Chester beds of Illinois) and the Coal Measures. Following this are articles by Professor C. L. Herrick, Dr. A. F. Foerste, and Mr. E. O. Ulrich, on various special groups (Lower Silurian, Clinton and Waverly). Chapter VI. by Professor Claypole and A. A. Wright describes the fossil fish of the Ohio shale and is a continuation of Professor Newberry's work in this line. With the exception of chapter VI., the descriptions here given have been for the most part already published elsewhere, so that particular comment seems to be unnecessary. Their especial value here consists in the fact that they have now been collected together, and by the generosity of the state become readily accessible to a much larger circle of scientific readers. The paper on the Clinton is a distinct addition to the somewhat scanty literature of this formation. Twenty-nine forms are found to be common to the Clinton of Ohio and the original Clinton of New York state, though the exact parallelism is not altogether clear, and on the other hand an examination of the cuts shows a strong resemblance, or indeed an identity of many of these Clinton with well-known Niagara types. Thus *Calymene Vogdesi* would seem to present no tangible points of difference from *C. Blumenbachi* and *Illænus madisonensis variety depressus*, as figured, could with difficulty be distinguished from *Illænus insignis* as figured by Hall (Twentieth Rept. N. Y. Mus., Pl. 22, Fig. 14). The author has, however, taken much pains to point out differences and likenesses of allied forms, and often frankly acknowledges the difficulties of separating Clinton and Niagara types.

E. C. Quereau.

Report on Surface Geology. By ROLLIN D. SALISBURY, in Annual Report of the State Geologist of New Jersey, for 1893, pp. 35–328. Pl. 1–6, and three large-scale, folded maps.

This is the third report of progress which has appeared on the detailed studies of the surface geology and topography of New Jersey now being made by the Geological Survey of that state. The results recorded are the outcome of the field work in 1893, conducted by Professor Salisbury, who was assisted for longer or shorter periods by Messrs. H. B. Kümmel, C. E. Peet, A. R. Whitson, and G. N. Knapp. The area examined is practically the northern third of the state. Observations were confined to the records of glaciers, and to certain gravel deposits more or less closely associated with ice invasions. The order of treatment is chronological, beginning with the oldest records that have been thought to belong to Pleistocene time.

The Yellow Gravel.—The occurrence of detached areas of gravel and sand, from the latitude of Staten Island southward has been known for several years, and usually designated as "Yellow Gravel," and referred in part to the Columbia and Lafayette formations. When traced southward, the areas occupied by this deposit became larger, and are believed to coalesce finally so as to form a continuous sheet, having a wide geographical range. Along its northern margin this deposit attains a maximum elevation of nearly 400 feet above the sea, and declines gently southward. It has usually been considered a single terrane, but the report before us proves that it includes at least four distinct deposits differing widely in age. Three of these divisions have been given local names as follows, beginning with the oldest: Beacon Hill, Pensauken and Jamesburg. The fourth and youngest phase is not named.

While the more obtrusive lithological characteristics of these four terranes are similar and in a general way are expressed by term Yellow Gravel, yet careful study has shown that they differ widely in composition and that the pebbles they contain were derived from widely separated sources. The Beacon Hill gravel is characterized by the presence of yellowish quartz, chert, flint and sandstone pebbles, and by the entire absence of shale and granitic material. The constituent pebbles range up to three inches in diameter, and cobbles and moderately worn slab-shaped fragments, two feet in diameter are occasionally found. In the Pensauken which was derived largely from the Beacon Hill, there is an addition of material from widely separated sources to

the north, much of which is of such a size and shape as to suggest that ice may have assisted in its transportation, though no glaciated material has been found in it. The advanced stage of decay observed in the pebbles and bowlders of this deposit shows that it has been long exposed to the action of the atmosphere, or perhaps more properly, to the percolation of surface water. The third deposit, the Jamesburg, is markedly heterogeneous. It is more loamy than the preceding, but contains cobbles and even bowlders of large size, some of which differ in character from those of the Pensauken, and were derived from different sources ; glaciated bowlders are occasionally found. An important change in geography, at least, if not in reference to glaciation, is thus indicated. The lithological characteristics of the fourth stage are not stated, but presumably they are such as would result from a working over and commingling of the material composing the three earlier deposits. It is thus evident that the lithological differences in the several divisions of the Yellow Gravel are sufficient in themselves to warrant a subdivision of what was formerly considered the record of a single period of deposition.

The Beacon Hill gravel was laid down on the even and uneroded surface of the Cretaceous. Elevation followed and stream channels were sunk through the gravel and into the marl beneath. In these channels in part, the Pensauken was deposited during subsequent submergence. In the Pensauken there are fragments of ferruginous concretions derived from the Cretaceous ; these are absent from the Beacon Hill gravel, showing as do other facts, that the Cretaceous terrane was not cut by stream channels until after the first division of the Yellow Gravel was laid down. Another elevation followed the Pensauken stage, and during a subsequent submergence the Jamesburg was spread over the channeled surface of the second deposit. The fourth stage of submergence was of minor importance ; its records are confined to the seaward margins of the region, and vary in elevation from twenty-five to forty-five feet. This is evidence of a moderate submergence subsequent to the Jamesburg stage, or may possibly represent a halt in the process of upheaval that closed that time of deposition. Thus, by unconformities, the Yellow Gravel is shown to belong to at least three periods of subsidence, separated by intervals during which the region was elevated and exposed to erosive agencies.

The Beacon Hill gravel is known from its stratigraphic position to be post-Cretaceous. While evidence of its precise position in the

geological column is lacking, there are reasons for believing that in part at least, it is Miocene. The last subdivision of the Yellow Gravel is thought to have been either contemporaneous with the last glacial epoch or more recent.

In reference to the length of time represented by these deposits, it is stated that the interval between the first and second divisions was probably much longer than the time which has elapsed since the second; and that the interval between the second and third stages was longer than the time since the third.

The relation of the later phases of the Yellow Gravel to Pleistocene glaciers, and the probability that the Jamesburg formation at least was deposited in part through the agency of floating ice, and possibly in the vicinity of glaciers, are discussed and the weight of the evidence indicated. The presence of a great variety of rock materials, including large bowlders, in the Pensauken, and the occurrence of that deposit beneath "extra-morainal glacial drift," seems to suggest that there may have been a time of glaciation of older date than the earliest evidence of glacial work otherwise recognized in the region studied. The absence of glaciated stone from the Pensauken, makes it impossible to connect this formation with the ice with any degree of certainty.

Extra-morainal drift.—The true nature and significance of certain detached areas of much weathered morainal material, south of the great terminal moraine that crosses northern New Jersey, has been the source of controversy, but the mass of evidence presented in the report before us must silence opposition, as the glacial origin of the material referred to is placed beyond all doubt. The distribution of this extra-morainal drift from the Delaware eastward, for about halfway across the state, is accurately mapped, but its extension in the lower country to the eastward is indefinite and seemingly indeterminate. Its maximum extent south of the terminal moraine is twenty-two miles, and the area more or less completely covered by it, about 450 square miles. This older drift occurs in detached areas and bears evidence of marked decay and extensive erosion. A large part of the region it once covered retains only scattered bowlders to show the nature of the former covering. The southern limit of the ice during this earlier invasion is approximately indicated on a large scale map which also presents much additional data concerning later glacial deposits.

The care with which the distribution, character, weathering, erosion, etc., of the extra-morainal drift has been studied and the amount of

evidence on which the conclusion as to its nature and age are based, may be judged to some extent by the fact that fifty pages are devoted to a detailed record of observations.

The terminal moraine.—Next in order in this historical study of Pleistocene of New Jersey come fresh observations concerning the great terminal moraine that crosses the state. The course of this prominent topographical feature has been re-traced and mapped with care, and the characteristics of its varied features described and their origin discussed. Attention is directed to the influence of pre-glacial topography on the trend of the moraine. Where the country is low and offered few obstructions to the advancing ice, the moraine extends farther south than on higher and more rugged areas. The same relationship between the trend of the moraine and the character of the antecedent topography, appears also when minor features are studied. Thus at the crossing of every pre-glacial valley the moraine bends southward showing that the valley facilitated ice movement. Local elevations on the other hand caused the moraine to recede from its normal course.

The moraine is a conspicuous topographic feature, especially when seen from its outer or southern face. In places it rises abruptly to the height of 140 feet above the over-washed gravel fringing its outer margin. Its inner or northern slope is not strongly pronounced and frequently merges with gentle gradations into the drift-covered country that it borders. The distinction between the moraine as a topographic feature and the topography of the moraine is emphasized. Special features in the relief of the moraine and characteristic examples of morainic topography are described and illustrated by sketches.

The characteristics of both the outer and inner margins of the moraine are described in detail, and many observations recorded in reference to its width, depth, and the character of the material of which it is composed. Its course and width, and the extent of the over-washed apron of gravel bordering it on the south, are shown on a large-scale map of the state.

Drift deposits made under the influence of stagnant ice.—The origin of certain gravel terraces with irregular margins and projecting spurs, occurring on the sides of valleys, is explained on the hypothesis that the centers of the valleys where they are found were formerly occupied by stagnant ice, and that sand and gravel were swept into depressions bordering it on either side, and into crevasses in its margins. A *mold* of the ice, as it may be termed, was thus formed. When

melting occurred, the gravel and sand were left in terraces with irregular valley slopes, corresponding with the irregularities of the ice against which they were deposited.

These terraces, and especially their projecting spurs, formed by the filling of crevasses, present many of the features of kames; they are therefore named *Kame Terraces*. This is a welcome addition to topographic nomenclature. The irregular outer margins and projecting spurs of kame terraces seem to make them specifically distinct from similar deposits formed on the borders of moving glaciers.

Drift phenomena of the Palisade Ridge.—The records of a detailed study of the glaciation of the Palisade trap ridge on the west side of the Hudson, occupies sixty-seven pages of the report. This long, even-crested monoclinal ridge, rising from 200 to 400 feet above tide, was crossed obliquely by the ancient glaciers and offered a stubborn resistance to their advance, as is shown by its worn and striated surface. Many measurements of the direction of striæ are shown on a large-scale map, which indicate that the average direction of the ice movement was about S. 44° E. In some instances there are two series of striæ on the same surface, as is common in many formerly ice-covered regions. The most probable explanation of these double records, according to Salisbury, seems to be that during the advance and again during the retreat of the ice, there were variations in its direction of flow, owing principally to the expansion and contraction of the glacial lobe under which the Palisade ridge was located.

All of the peculiar markings known to have been made by glaciers on rock surfaces, such as striæ, grooves, chatter marks, disruption gouges, etc., were discovered on the Palisade Ridge, as well as perched bowlders, *roches moutonnèes* and other similar records. The till covering a large part of the ridge presents interesting features, among which are blocks of sandstone, at elevations from 300 to 500 feet above the ledges from which they were derived, and illustrating the lifting power of glaciers.

The borders of the Palisade Ridge, especially on the northwest—the direction from which the ice came—are in places heavily encumbered with stratified gravel and sand, which record the abundance of the drainage from the melting ice.

A yellow loam occurring in detached areas at various elevations on the Palisade Ridge is the subject of several ingenious hypotheses. The most plausible explanation of its origin seems to be that it was accumu-

lated on the ice, partially as dust, and left on the surface of the till when the melting occurred. The fact that superglacial material, especially on stagnant ice-sheets, is subjected to many changes of position and experiences many falls, and is thus broken, and that it is also disintegrated on account of changes of temperature, might, it seems to the present writer, be cited in connection with the hypotheses suggested in reference to superglacial origin of the loam.

Lake Passaic.—The conclusion that a large glacial lake formerly existed in the drainage basin of Passaic River, in north-central New Jersey, was advanced by Professor George H. Cook, the late state geologist, in his annual report for 1880. The strength of the evidence on which this conclusion was based has since been questioned, and several geologists who have visited the region have doubted if Lake Passaic, as the old lake was named, ever had an existence. This subject has been restudied by Salisbury and Kümmel, and so much consistent evidence advanced that the former presence of the water-body referred to must not only be accepted, but given a prominent place among examples of ice-dammed lakes of the nature of Merjelen Lake, Switzerland, the first existing example of the type to be studied.

The trap ridges of central New Jersey, rising above low-lying areas of Newark sandstone and shale, have such a form that an ice-sheet advancing from the north would occupy the depressions through which the drainage escapes, and thus shut off a considerable basin from free discharge to the sea. This in general was the history of the origin of Lake Passaic. The evidence furnished by lacustral deposits, terraces and other shore features, as well as by the position of the great terminal moraine, although indefinite at times and seldom pronounced, is, on the whole, sufficient to prove the former presence of Lake Passaic and to admit of the mapping of its shores. Like most lakes held by ice dams, the glacial lake of New Jersey had a varied history, several chapters of which have been deciphered. During its maximum it was about thirty miles long from north to south and ten miles broad at its widest part, and over 225 feet deep.

Since the lake was drained, the region it occupied has undergone changes in elevation and the old shore lines are no longer horizontal. An increase in elevation from south to north of sixty-seven feet in thirty miles, or at the rate of 2¼ feet per mile, has been shown to exist. These changes are supposed to be due to a re-adjustment of isostatic conditions after the disturbances produced by the weight of the Pleistocene ice-sheets.

This admirable report of progress, covering nearly 300 pages and accompanied by three large-scale maps and dealing with the surface geology of perhaps one-third of New Jersey, establishes a precedent that those in charge of other geological surveys will do well to follow. It will no doubt be a surprise to many who read the topographic history of New Jersey as interpreted by Salisbury, to learn that in the surface features of the land there is preserved a record that is fully as interesting and instructive as the history of past faunas and floras, which for a long time was considered the special field of the geologist.

Geologists and geographers alike will await with interest the appearance of the final monograph of the surface features of New Jersey, which the reports of progress already issued lead them to expect.

ISRAEL C. RUSSELL.

Bulletin of the Geological Society of America. Vol. VI., pp. 103–140; Pl. 1. *Reconstruction of the Antillean Continent.* By J. W. SPENCER, A.M., Ph.D., F.G.S. (L. & A.). January, 1895.

In this paper the author arrives at some very striking conclusions concerning the elevation of the Antillean island during Pliocene and early Pleistocene times. The deep depressions, which cross the continental shelf and which are believed by the author to be drowned valleys, furnish him data by which to estimate the amount of such elevation. Between Cape Hatteras and the Bahama Islands four clearly marked depressions cross the continental plateau. Three of them are in line with rivers of the coastal plain. These fjords can be traced for distances between 200 and 300 miles, and into water 12,000 to 14,000 feet deep. One of them sinks over 5000 feet below the level of the submerged plateau and is comparable to the Grand Cañon of the Colorado. Between the Bahama islands are depressions traceable for distances up to 350 miles, and from depths of about 2000 feet into waters 10,000 to 14,000 feet deep. In the Gulf of Mexico similar submerged valleys exist, and in most cases they are closely related in position to existing rivers. They are traceable into water 10,000 feet deep. Their bottoms sink from 800 to 3000 feet below the top of the valley sides, and they are several miles in width. Other fjords occur off the coasts of the West Indies, and around the Caribbean Sea, some of which are traceable into depths of 12,000 feet.

The author concludes that these are land valleys which have been

greatly depressed. He bases his conclusions, (1) upon their general resemblance in contour to land valleys, and (2) upon their direct connection (in most cases) with existing rivers, save where such connection has been manifestly obliterated or obscured by recent coastal deposits. In many respects these depressions resemble land valleys, and the author's conclusion has a strong basis of probability. The following consideration may, however, be urged against his view. If these depressions are drowned land valleys, the soundings ought to show the existence of great deltas at their mouths. The author makes no mention of such deltas and the inference is that they do not exist. Their absence, so far as known, is a serious objection to the author's view.

The logical inference from Mr. Spencer's conclusion respecting these fjords is that the land formerly had a much greater elevation than at present. Assuming that the depth to which the mouths of the fjords are now submerged is nearly the exact measure of the former elevation of the continent, and making a small allowance for foldings and amplified marginal depressions, Mr. Spencer concludes that this elevation was not less than 8000 feet along the northern shore of the Gulf of Mexico, about 12,000 feet in the vicinity of Yucatan, 10,000 or 12,000 feet for the Greater Antilles and nearly the same for the southeastern margin of the continent. The soundness of this assumption will be considered later. Waiving for the moment this point, let us note the author's conclusions.

In the West Indies Mr. Spencer has found two series of deposits which he correlates with the Lafayette formation and with the older Columbia series. To these he gives the names Matanzas and Zapeta, respectively. They are separated from each other by strongly marked unconformities. The Matanzas is likewise separated from the upturned and deeply eroded Miocene beds by a great unconformity. Combining the data furnished by these deposits with the quantitative element furnished by the fjords, the author reaches the following conclusions as to the oscillations of the land. From an elevation toward the close of the Miocene much lower than at present, the land in the Pliocene was elevated according to location from 8000 to 12,000 feet higher than at present. The close of the Pliocene saw the Antilles and the neighboring parts of the main land 100 to 1100 feet lower than at present. During this depression the Matanzas limestone was formed. This subsidence was followed by a re-elevation in early Pleistocene times, probably as great as that of the Pliocene. The fjords crossing the

continental shelf were first excavated during the Pliocene, and then re-excavated — so far as filled during the Matanzas depression,— and deepened during the Pleistocene elevation. Later in the Pleistocene the land sank to a level 25 to 500 or 700 feet below the present elevation and the Zapeta loams and gravels were formed. Minor oscillations, not yet well worked out, have since taken place.

The most important conclusion of this paper, *i. e.*, the amount of the elevations, is based upon the assumption that the continent stood as much above sea level as the fjord bottoms are below it, less some correction for unequal subsidence of the continental area. Although granting that a correction should be made for unequal subsidence, the author seems, so far as appears from his paper, to have practically neglected this point in his calculation of the former elevation of the land. The amounts of elevation which he gives for the various regions are almost as much as the amounts by which the fjord bottoms lie beneath the sea level. It seems possible to account for the depths to which the mouths of the fjords are submerged, without assuming that the continent stood at such heights.

Grant that the elevation was sufficient to permit streams to cut valleys across the continental shelf hundreds of feet deep, and in one instance, at least, to excavate a cañon comparable to the Grand Cañon. It is probable that subsidence, once started, would be greater along the edge of the continental shelf than further inland. This would naturally follow on the doctrine of isostasy from the loading of the outer part of the continental shelf by sediments, deposited as the shore line advanced inward. It seems highly probable that the subsidence would be of the nature of a seaward tilting of the land and a deepening of the ocean basins.

Such differential motion along lines normal to the coast would increase the gradient of the bottoms of these buried channels. Before the author's hypothesis of practically uniform subsidence along normals to the coast can be accepted, it is incumbent upon him to show that the above hypothesis of subsidence with great tilting is inapplicable to the case in hand. So far as known to geologists, all epeirogenic movements are in the nature of tiltings and warpings rather than rigid uniform changes. If the subsidence were uniform or varied only along lines roughly parallel to the coast, the buried channels would retain practically the same gradient as they had when land valleys. A rough means of testing this hypothesis is thus at hand.

If the gradient of the fjords is much greater than that of land valleys, which most closely correspond to them in width and depth, the conclusion that the land "stood as high as the fjords are deep" would seem not to be warranted. Moreover, if the subsidence along normals to the coast was equal, the gradients of the bottoms of the fjords would be less than the gradients of the rock bottoms of the rivers, of which the fjords are continuations. For the gradient of a valley is always greater nearer its head than in its lower part, if the rocks are not greatly different in the two parts of the course. Further, the rivers of the coastal plain meander in wide valleys, now filled to a considerable depth with alluvial deposits. The width of these valleys compared to their depth, where known, shows that they were well advanced in the cycle of erosion, and that their gradients must have been comparatively low. If this be true for the valleys of the coastal plain, to a much greater degree must it be true for the submerged parts of these valleys across the continental shelf. From what is known of the dimensions and contours of these fjords, a low gradient can be confidently predicted, unless the continental shelf has been tilted seaward.

From the data given, the gradient of a few of these fjords can be estimated. The Bahaman valley has an average fall of twenty-four feet per mile for 350 miles; the Floridian, of twenty-five feet per mile for 400 miles; the Cazones, of seventy feet per mile for seventy-five miles, and the Altamahan, of nineteen feet per mile for 300 miles. These gradients are much greater than those of corresponding land valleys. The Grand Cañon of the Colorado has an average fall of less than eight feet per mile for 284 miles.[1] Judging from borings in the alluvium deposits of the Mississippi at New Orleans and Memphis, the rock bottom of the river between these two points has a gradient of but little more than two feet per mile. Since it is not certain that these borings reached the deepest part of the valley at their respective localities, the gradient may be more than this; it may, however, be less. But in spite of this element of doubt it is absolutely certain that the gradient is much less than that of the submerged valleys. The gradient of the fjords, considered in respect to the size of these valleys and compared with the low gradient of land valleys strongly favors the hypothesis that the subsidence was much greater remote from the present coasts, than it was along the shore. It cannot, therefore, be safely concluded that because the mouths of these fjords are now submerged to depths from 10,000 to

[1] DUTTON: United States Geological Survey, Monograph II., p. 240.

12,000 feet or more, that the whole Antillean continent stood an equal amount above its present level.

The bottom of the fjords, particularly the landward portion, have probably been somewhat filled with sediments. The gradients as calculated from the soundings may be too great. But it is not probable that the possible error from this cause can bridge the discrepancy between gradients of the fjords and those of similar land valleys. The facts given by Mr. Spencer prove a greater elevation of the continent in Pliocene and in early Pleistocene times than at present, and a lower level at the end of the Pliocene and later in the Pleistocene. It may be fairly questioned, however, whether they prove the great elevation above the present level which is claimed.

HENRY B. KÜMMEL.

Elements de Paléontologie. By FELIX BERNARD, Paris, 1895; 1146 pages, 606 illustrations, Baillaire & Son.

A new palæontology bringing up to recent date the more important results of work in this field will be welcome to many. It includes a phytological as well as zoölogical portion, though the *Invertebrata* are more fully treated than the remainder. Morphology and classification are treated with especial fullness, though the latter is carried down only as far as the family or, usually, the genus. The phylogeny and embryology of groups is also given in summary at the close of the different sections. The sections on the brachiopods and the crinoids are especially well developed, and the introductory chapter of the book in which the scope of palæontology and its relations to other sciences is discussed will be found of especial interest.

E. C. QUEREAU.

THE

JOURNAL OF GEOLOGY

MAY-JUNE, 1895.

MESOZOIC CHANGES IN THE FAUNAL GEOGRAPHY OF CALIFORNIA.

CONTENTS.

INTRODUCTION.

THERE is probably no region where the successive faunas have been a genetic series. With each new set of rocks species, genera, families appear without local forerunners and disappear without leaving local descendants. Thus the distribution of

genera varies greatly in successive periods. These changes have been due to migration; each rising of a seacoast, or transgression of sea on land areas, or connection of basins that before were separated, has added to the confusion of faunas, bringing in new elements, while many of the old were forced to migrate, or else were unable to survive the new conditions and increased natural competition with vigorous immigrants.

Marine invertebrates migrate chiefly through their young, and along shore lines, where the successive generations can find the same conditions suitable to their perpetuation, and the young are especially sensitive to changes in temperature and food-supply. Therefore marine currents along continental borders are very favorable to migration, since by them the same conditions necessary for life are spread far out of their usual range.

If the naturalist would trace out the life history of genera and species, he must not confine his studies to a single region, for there the history is made up of disconnected episodes. He must seek the regions from which the faunas came and follow out their migrations into regions to which they departed, must find out what regions contributed certain new elements to the population and must learn the order of appearance of a fauna in different parts of the earth. In this way alone can he get a true idea of the changes which forms have suffered, and the reason of these changes, the mutual working of the laws of natural selection and adaptation to surroundings. In this way, too, he can get a true history of the inhabitants of the earth, and of the changes in physical geography at various periods, the primary object of geologic investigation.

The study of the faunal relations of the various series of sedimentary rocks of California has proved exceedingly interesting and has thrown much light on past changes in physical geography. Some of the facts obtained seem to conflict with the theory of the permanency of continental plateaux and oceanic troughs.

The writer has, therefore, undertaken to outline the faunal relations which California had with various regions during differ-

ent periods of geologic history, and the probable changes in physical geography that accompanied and caused this shifting of relations. The Mesozoic era has been taken as a basis because the faunas of that time are better known, and because the physical geography of that time has been better worked out all over the earth. But the changes which preceded the Mesozoic era will also be outlined as far as they are known. And since California is intimately connected with other regions of the West Coast, these regions will also be considered in so far as they concern California.

PRE-CARBONIFEROUS RELATIONS.

Cambrian and Silurian.—The Cambrian and Silurian of California, as described by Professor C. D. Walcott[1] in the papers cited below, are too little known for any opinion about them to be decisive; they are, however, probably like the Cambrian and Silurian as it is known in Nevada and the West in general.

Devonian.—In California the Devonian is little known, having been described by J. S. Diller and Charles Schuchert[2] from only a few places in Shasta and Siskiyou counties, and the forms that occur there give little clue to the affinities with other regions. But from the study of the faunas of other parts of America we get some light on the geography of the Devonian.

The work of Dr. A. Ulrich[3] has made it clear that during the Lower and Middle Devonian the faunas of North America were closely related to those of Bolivia, Brazil, the Falkland Islands, and South Africa, but that they were different from those of Europe. But Professor H. S. Williams[4] has shown that at the beginning of the Upper Devonian in North America there came in many species whose ancestors are not found in the Middle Devonian of that region. This fauna, however, is closely related

[1] Am. Jour. Sci., III. Series. Vol. XLIX., pp. 141–144, and Bull. Geol. Soc. Amer., Vol. III., p. 376.

[2] Am. Jour. Sci., III. Series, Vol. XLVII., pp. 416–422.

[3] Beiträge zur Geol. und Pal. von Südamerika, I. Paläozoische Versteinerungen aus Bolivien.

[4] Bull. Geol. Soc. Amer., Vol. I., Cuboides Zone and its Fauna, and Proc. A. A. A. S., 1892, Sec. E., Address; Scope of Paleont. and its Value to Geologists.

to that of Europe and Asia while quite different from that of the southern regions.

This striking change in the faunal relations of North America means something more than a mere migration; it means that in Lower and Middle Devonian times some barrier cut off the European and Asiatic faunas from those of America, and that in the Upper Devonian this barrier was removed while one was interposed between the northern and the southern regions. Professor W. Waagen[1] has shown that this continued during the Carboniferous and Permian.

CARBONIFEROUS FAUNAS.

Lower Carboniferous.—In a previous paper[2] the writer has shown that the Lower Carboniferous fauna of California was derived directly from the preceding Devonian, since so many species that in the Mississippi Valley or eastern region would be considered characteristic of the Devonian still survive. This survival has been used by Professor H. S. Williams,[3] and the writer,[4] to show that the reappearances of older forms in younger rocks have been due to migrations consequent upon the shifting of physical barriers.

Affinities of the fauna.—The Lower Carboniferous, or Baird Shales, fauna of California is intermediate in character, as it is in geographic position between the eastern American and the Russian and Asiatic. It differs from the typical American fauna in the survival of so many Devonian types and the presence of some Eurasian elements. It belongs to the zone of *Productus giganteus* or the lower part of C_1 of the Russian section.

Upper Carboniferous.—The Upper Carboniferous fauna of California seems to have been developed directly out of older species in the same region, since there is known no complication of elements brought in by the migration from outside the Pacific Car-

[1] Palæontologia Indica, Salt Range Fossils, Geological Results.

[2] JOUR. GEOL., Vol. II., No. 6, The Metamorphic Series of Shasta County, California.

[3] Am. Jour. Sci., III. Series, Vol. XLIX., pp. 94–101.

[4] JOUR. GEOL., Vol II., p. 198, and Vol. II., p. 598.

boniferous region. Again here we see the intermediate characteristic between the eastern American and Eurasian faunas, but the affinities are closer with the latter.

The McCloud limestone corresponds to the upper part of C_1, and the lower part of C_2 of the Russian section. The upper part of the McCloud limestone is, therefore, homotaxial with the zone of *Omphalotrochus whitneyi*, Meek. This species was first described from the McCloud limestone, but has been found in eastern Russia near the top of C_2 in such large numbers as to give name to the zone.

Artinsk beds.—The argillites above the McCloud limestone are the equivalents of the Robinson beds of the Taylorsville region and of the Little Grizzly creek beds of Plumas county. These are probably homotaxial with the top of C_2, and the lower part of the Artinsk stage of Russia. They contain the following species closely related to forms of the Russian Artinsk stage, and the Productus limestone of the Salt Range in India :

Marginifera conf. *splendens*, Norwood and Pratten.
Productus conf. *cora*, d' Orbigny.
" conf. *scabriculus*, Martin.
" conf. *spiralis*, Waagen.
" group of *P.*, *abichi*, Waagen.
Streptorhynchus conf. *pelargonatus*, Schlotheim.
Camarophoria conf. *purdoni*, Davidson.
Dielasma elongata, Schlotheim.
Spirifer interplicatus, Rothpletz.
S. (*Reticularia*) *lineatus*, Martin.
S. wynnei, Waagen.

In addition to some of these, the Robinson horizon of Plumas county contains a very long slender *Fusulina* that agrees closely with *F. longissima*, Möller from the Salt Range.

Of the above mentioned species *Marginifera* conf. *splendens* is the form usually identified with *Productus longispinus*, Sowerby in the Western Upper Carboniferous. *Productus* conf. *spiralis* is only a mutation of *P. semireticulatus*, Martin ; *Spirifer wynnei* is a modification of *S. striatus.* Thus this fauna stands to the Carboniferous forms as mutations, showing only a slight difference in

age. It appears quite probable that they belong to the Artinsk stage, but it is also quite possible that they are homotaxial with the uppermost Coal Measures, because at the top of C_2 of the Russian Coal Measures many Permian species appear.

The inhabitants of the Eurasian and the North American Carboniferous seas belong to one type, the northern of Waagen,[1] and were separated from the southern regions.

POST-PALÆOZOIC REVOLUTION.[2]

Towards the end of the Carboniferous the greater part of the North American continent was raised above water; this revolution, or revolutions nearly contemporaneous with it, was very widespread, so that the break between the Palæozoic and Mesozoic has never been bridged over. Quite recently, however, Professor W. Waagen[3] has described from northwest India a set of fossils younger than the latest Permian and older than the oldest known Trias. But even here these forms are continuous with the Trias, but separated from the Permian by a break in life. In the West, therefore, the Triassic species are not descendants of the preceding local Palæozoic forms, but are foreigners, brought in by migration from regions as yet unknown. This itself, if we had no other proof, would be sufficient evidence that there must have been great stretches of continental margin where these faunas could develop, and that these breeding grounds have been mostly obliterated by the sea, so that we find their remnants in only a few places, such as the Salt Range in India.

TRIASSIC FAUNAS.

Lower Trias.—Even if we do not know where to look for the ancestors of the Triassic animals, we know well where to look for their contemporary kinsfolk. In California as yet no Lower Triassic fossils have been described; but rocks are here that are probably of that age, so that the finding of fossils is only a question of time.

[1] Salt Range Fossils, Geol. Results, p. 239.

[2] See TSCHERNYSCHEW, Mem. Com. Geol. Russie, Vol. III., No. 4, p. 364.

[3] Jahrbuch. K. K. Geol. Reichsanstalt Wien, 1892, Vol. XLII., Vorläufige Mittheilung ueber die Ablagerungen der Trias in der Salt Range.

But near by, in southeastern Idaho, are found Lower Triassic[1] fossils, of which the most characteristic are *Meekoceras gracilitatis*, White, *M. mushbachianum*, White, and *Xenodiscus aplanatus*, White. Very closely related forms have been described from the Salt Range of India by Waagen,[2] and from northern Siberia by Mojsisovics,[3] and from the Himalayas by Griesbach.[4] It is clear then that the post-Palæozoic revolution had not cut off the West Coast region from direct connection with the Indian and Arctic provinces. But these two provinces were probably cut off from the Mediterranean province, since it has been shown by Mojsisovics[5] that during Lower Triassic time *Tirolitinæ* were common, *Dinaritinæ* rare, but *Meekocerata* almost unknown in the Mediterranean region; while in the Arctic province there were no *Tirolitinæ*, but many *Dinaritinæ* and *Meekocerata*. Also Waagen[6] has recently shown that the same thing is true of the Salt Range and Himalayan Lower Triassic faunas.

The Idaho beds were, therefore, deposited on the extreme eastern border of a sea that stretched from the Salt Range eastward to America, and northwards to Siberia. And for the Lower Trias alone the Arctic-Pacific Trias province of Mojsisovics will hold good. In this province somewhere we have to seek for the ancestors of the *Ceratitidæ*, which Mojsisovics[7] says will be found among some of the *Meekocerata*, while Karpinsky[8] thinks it probable that the *Meekocerata* descended from the goniatite stock *Prolecanitidæ*.

Middle Trias.—Rocks of the Muschelkalk series are only doubtfully known in California, but a comparatively rich fauna of this age has been described from the Star Peak range in

[1] C. A. WHITE: Twelfth An. Rep. U. S. Geol. Surv. Terr., Part I., pp. 105–118.

[2] Pal. Indica, Salt Range Fossils, I. Productus Limestone Fossils, Cephalopoda.

[3] Mém. Acad. Impér. Sci. St. Pétersbourg, Series VII., Tome XXXVI., No. 5. Arktische Triasfaunen.

[4] Records Geol. Surv. India, Volume XIII. Part I., 1880.

[5] Arktische Triasfaunen, p. 149.

[6] Jahrb. K. K. Geol. Reichsanstalt Wien, Vol. XLII., 1892, pp. 384–5.

[7] Abhandl. K. K. Reichsanstalt Wien, Vol. VI., Part II., Cephal. Hallst. Kalke II. Part, p. 7.

[8] Ammoneen der Artinsk-Stufe, p. 43.

Nevada, by F. B. Meek.[1] This fauna has been shown by Mojsisovics[2] to possess certain elements unknown to the Arctic Lower and Middle Trias; these are *Trachyceras*, *Acrochordiceras*, *Eutomoceras*, *Arcestes*, and *Orthoceras*. But of these *Acrochordiceras*, *Arcestes* and *Orthoceras* are present in the Muschelkalk of the Mediterranean Trias province. *Trachyceras* is the culmination of the stock of *Tirolitinæ*, which according to Mojsisovics are wholly lacking in the Arctic Lower and Middle Trias, but are common in the Mediterranean province; to the latter region, then, we must look for the derivation of the Western *Trachycerata*.

Eutomoceras is a member of the *Tropitidæ*, which are unknown in the Mediterranean province during Middle Trias; their remote relative, *Sibirites*, is common in the Lower Trias of Siberia, and may have been an ancestral stock of the *Tropitidæ*, whose more remote progenitors, according to Mojsisovics,[3] are probably to be found among the *Gastriocerata*, which group is not uncommon in the American Upper Carboniferous.

We see, then, among the Western Middle Trias forms a considerable infusion of Mediterranean elements, showing that intermigration between the two regions has begun, but that intimate connection with the Arctic province still exists.

Upper Trias.— In California rich faunas of the Upper Trias have been described from Plumas county by W. M. Gabb[4] and Professor A. Hyatt,[5] and from Shasta county by the writer.[6] These faunas show an intimate connection with the Himalayan and Mediterranean provinces, but only a few species in common with the Upper Trias described from British Columbia by J. F. Whiteaves.[7]

The Upper Trias, Noric and Karnic, of Plumas and Shasta counties has yielded the following species thought to be

[1] Geol. Exploration Fortieth Parallel, Vol. IV.

[2] Arktische Triasfaunen, p. 148.

[3] Abhandl. K. K. Geol. Reichsanstalt Wien, Vol. VI., Part II., second half, p. 7.

[4] Palæont. Calif., Vol. I.

[5] Bull. Geol. Soc. Am., Vol. III., pp. 395–412.

[6] Jour. Geol., Vol. II., No. 6. Metamorphic Series Shasta County.

[7] Geol. Survey Canada. Contrib. Canad. Pal., Vol. I., Part II., pp. 127–149.

identical with, or nearly related to, forms described from the Tyrolean Alps:

Eutomoceras sandlingense, Hauer.
Isculites conf. *obolinus*, Dittmar.
Juvavites Group of *J. ehrlichi*, Mojsisovics.
Sagenites conf. *herbichi*, Mojsisovics.
Tropites conf. *dittmari*, Mojsisovics.
" aff. *marii*, Mojsisovics.
" conf. *sellai*, Mojsisovics.
" *subbullatus*, Hauer.
" *torquillus*, Mojsisovics.
Badiotites aff. *eryx*, Mojsisovics.
Polycyclus henseli, Oppel.
Trachyceras conf. *aon*, Muenster.
" aff. *archelaus*, Laube.
Tirolites (*Metatirolites*) *foliaceus*, Dittmar.
Nannites conf. *spurius*, Muenster.
Nautilus triadicus, Mojsisovics.
Halobia lommeli, Wissmann.
" conf. *rugosa*, Mojsisovics.
" *superba*, Mojsisovics.
Monotis salinaria, Schlotheim.

Many of these species also occur in the Himalayas, although until the completion of Mojsisovics' monograph on the Himalayan Upper Trias no exact comparison with that region is possible.

The above list shows that in California, as in the Himalayan and the Mediterranean provinces, with the beginning of the Karnic stage of the Upper Trias there came in from some unknown region a swarm of *Tropitidæ*. It is interesting to note that during this period the Salt Range fauna seems to have preserved its Arctic character, and to have been cut off from the sea in which the faunas of the Mediterranean, the Himalayan and the Californian provinces lived.[1] Again here we see an indication of a great change in physical geography, that has left no other record than the incursion of an exotic fauna.

JURASSIC FAUNAS.

Lias.—A marked hiatus separates the Lias of California from the Trias, as is the case everywhere else; the *Tropitidæ* and

[1] W. WAAGEN: Jahrb. K. K. Geol. Reichsanstalt Wien, Vol. XLII, 1892, p. 385.

Ceratitidæ have died out, and again a new fauna comes in from unknown regions. The lower Lias of California and Nevada, according to Professor A. Hyatt,[1] is characterized by the presence of *Arietidæ* of European habitus although not identical with European species.

The Lias[2] is typically developed over western Europe, and as far to the southeast as the Caucasus Mountains, but wholly unknown in eastern Europe, eastern Africa and continental Asia.

In the work cited, Neumayr has shown from the distribution of fossils and sediments during the Lias that then eastern Europe, nearly all Africa and Asia were above water, since Jurassic land-plants are found over much of this area; but on Japan is found Lias of European type.

Dr. O. Behrendsen[3] has recently described from the Argentine Republic lower Lias, with typical European species of *Arietidæ* and *Amaltheidæ*. The same type of Lias, with *Arietites geometricus*, Oppel, and *A. longicellus*, Quenstedt, has been described by Dr. A. Rothpletz[4] from Timor in the Indian Ocean. These species could not have migrated to or from Europe by the western way, since this was blocked by the continental mass at the junction of Europe, Asia and Africa. They along with the American species could only have migrated by the eastern way through the "Central Mediterranean Sea."[5] In this way we have in the Lower Jura of California a central European type of fauna.

Middle Jura.—The fossils of the Californian Middle Jura are too little known for us to be able to speak with certainty about their faunal relations, but the few species that have been described by Professor A. Hyatt[6] are probably of central European type.

[1] Bull. Geol. Soc. Am., Vol. V. Trias and Jura in the Western States.

[2] M. NEUMAYR: Denkschr. K. Akad. Wiss. Wien., Vol. L, 1885, Geograph. Verbreitung der Juraformation.

[3] Zeitschr. Deutsch. Geol. Gesell., 1891, p. 371.

[4] Palæontographica, Vol. XXXIX., p. 97.

[5] M. NEUMAYR: Geographische Verbreitung der Juraformation.

[6] Bull. Geol. Soc. Am., Vol. III., pp. 395–412.

Upper Jura.—The Upper Jura of California has been described from Plumas county and from the Mariposa formation of the Gold Belt by F. B. Meek in Vol. I. of the "Palæontology of California;" by Professor Hyatt,[1] and by the writer.[2]

The fossils described by Professor Hyatt from the Callovian and Corallian of Plumas county are of rather indecisive character, but seem to have their nearest affinities with central European species. This makes it probable that throughout the Callovian and part of the Oxford these waters were still connected with the central European. But at this same time there existed in the region of the Black Hills of Dakota and the Rocky Mountains a basin that contained a different fauna, and according to Professor Hyatt[3] was separated from the Californian basin. This central basin contains what Neumayr[4] has shown to be a decidedly Boreal fauna. In the paper referred to, Neumayr divided the Jura of the northern hemisphere in three distinct types, equatorial, temperate and Arctic. The Arctic or northern type occurs chiefly in Russia, and is characterized by the prevalence of *Cardioceras* and *Aucella*, and the absence of reef-building corals. Neumayr[5] has shown that the Black Hills Jura is a southern extension or bay of the Arctic sea.

It therefore becomes probable that during Oxford times the California area was still connected directly with the central European waters by way of the "Central Mediterranean Sea," and that the Black Hills basin was cut off from this, but connected with the Boreal sea of Russia.

Transgression of Upper Malm.—It has long been known that in Europe in the Middle Jura the sea began to transgress eastwards over the land until in the Upper Jura or Malm all eastern Europe and nearly all Asia were under water. This has been described by Neumayr[6] as one of the most striking events in

[1] Bull. Geol. Soc. Am., Vol. III., pp. 395–412; and Vol. V., pp. 395–434.

[2] Bull. Geol. Soc. Am., Vol. V., "Age of the Auriferous Slates of the Sierra Nevada."

[3] Bull. Geol. Soc. Am., Vol. III., p. 410.

[4] Denkschr. K. Akad. Wiss. Wien., 1883, pp. 301–302.

[5] Loc. cit.

[6] Geographische Verbreitung Juraformation, pp. 126–129.

geologic history, and one extending all over the northern hemisphere. But it becomes probable that while Eurasia was sinking, North America was rising, and that the eastward connection with European waters was cut off, for with the Kimmeridge there came in a fauna that no longer had any affinities with the central European, but rather with the Russian. This fauna has been described in the above mentioned papers by F. B. Meek, Professor A. Hyatt and the writer, from the Mariposa formation of the Gold Belt of California, also by Professor Nikitin[1] from San Luis Potosi in Mexico.

This type is characterized by the presence of *Cardioceras* of the group *C. alternans* and *Aucella* allied to *A. pallasi* and *A. bronni*.

There was, therefore, an elevation of a large part of America and also a transgression of the Boreal or Russian sea along the west coast as far as Mexico. This movement was correlative with the great Jura transgression of Eurasia.

It is a remarkable fact that this same fauna is found in the Spiti shales on the north side of the Himalaya Mountains while the Upper Jura of Kutch on the south side is of decidedly central European character. Neumayr[2] considers the Himalayan Jura a southward prolongation of the Boreal sea and the Kutch formation a prolongation of the central Mediterranean which also sent down a long gulf to Mombassa on the east coast of Africa. These African and Indian waters were separated from the western American by the ancient Australo-Asian continent, over which no marine Jura occurred, but widespread fresh-water deposits with Jurassic plants. Remains of this continent are still seen in Australia, New Zealand, and the submarine plateau on which are the islands that separate the Pacific from the Indian Ocean.

During all this time the Upper Jura of South America, as described by Dr. O. Behrendsen,[3] retained its central European

[1] Neues Jahrb. Min. Geol. und Pal., Band 2, 1890, p. 273.

[2] Geographische Verbreitung der Juraformation, pp. 109–117.

[3] Zeitschr. Deutsch. Geol. Gesell., 1891, pp. 369–420, and 1892, pp. 1–42.

character, having many species in common with that region, but being entirely cut off from the Californian.

CRETACEOUS FAUNAS.

Knoxville.—At the beginning of the Lower Cretaceous of California, as in the Upper Jura, we find that the closest affinities with foreign faunas are with the Volga stage of Russia. These beds and their faunas have been described by W. M. Gabb in the Palæontology of California, by J. S. Diller and T. W. Stanton,[1] and a similar fauna has been described from Queen Charlotte Islands by J. F. Whiteaves.[2] In the papers cited it has been shown that of the Knoxville fauna the following species are nearly related to Russian forms: *Aucella piochi*, Gabb, very near *A. mosquensis*, Buch; *A. crassicollis*, Keyserling, probably identical with the Russian species; *A. piochi*, var. *ovata*, possibly identical with *A. terebratuloides*, Lahusen; *Olcostephanus* aff. *discofalcatus*, Lahusen. And besides these there occurs *Hoplites* aff. *ambligonius* N. and U. These are sufficient to show a close faunal connection with Russian waters.

In addition to the species mentioned there are others of a Tithionan aspect, so that we have certainly the lowest Cretaceous and possibly the top of the Jura. Mr. Diller, in his various papers, has shown that the lowest Knoxville beds are separated from the highest Jura by a decided unconformity, but this does not represent any long time interval, and is not accompanied by any great change in life. The faunal geography was the same as at the close of the Mariposa epoch, and no new elements had come in; the change was due to development and intermigration between this region and Russia. Rocks of this age are unknown in India, so of the relation with southern Asia nothing can be said.

Horsetown.—In the Horsetown, or Gault, fauna it is seen that a great change has taken place; these beds lie conformably on the Knoxville, yet the Russian elements have nearly all died out,

[1] Bull. Geol. Soc. Am., Vol. IV., pp. 205–224; Vol. IV., pp. 245–256; Vol. V., pp. 435–464.

[2] Geol. Survey Canada, Mesozoic Fossils, Vol. I., Parts I. and III.

and a new fauna has come in, of which the majority could not have developed out of Knoxville forms, but are of southern type. This fauna is found in southern India, where it has been described by Stoliczka in the Palæontologia Indica.

The Horsetown[1] beds of California have yielded the following species thought to be identical with species from the Ootatoor group (Gault) of southern India:

Lytoceras sacya, Forbes.
Schloenbachia inflata, Sowerby.
Haploceras beudanti, Brongniart.

Besides these *Acanthoceras mamillare*, Schlotheim, unknown in India, is also found in the Horsetown.

The lower beds of Queen Charlotte Islands have yielded the above Indian species, and in addition to them several others as yet unknown in California. These species are nearly all also found in the Gault, Lower Cretaceous, of central Europe.[2]

Thus the Californian fauna has lost entirely its Boreal aspect since there was no longer any connection with Russia; rocks of this age are little known in that part of Europe.

Upper Cretaceous — Chico. — It has been shown by J. S. Diller and T. W. Stanton, in the papers cited above, that the Chico rocks and the Chico fauna are simply a continuation of the Horsetown. No Chico species are referred to European or Indian species, but many have near relatives in those regions. But the connection was still kept up, for the Upper Cretaceous of Vancouver Island still shows the presence of Indian types. On the other hand there seems to have been little connection with the interior region.

During the Cretaceous there was a revolution in the West, for in California the uppermost Cretaceous and the lowest Eocene are lacking. But we do not know how extensive this was, since

[1] See the papers of J. F. WHITEAVES, J. S. DILLER and T. W. STANTON cited above.

[2] A paper by Mr. F. M. ANDERSON on Some Cretaceous beds of Rogue River Valley, Oregon (this number JOURNAL GEOLOGY), materially increases the list of Indian species on the West Coast, but all the facts stated about the Cretaceous were taken wholly from previously published works on the subject.

the Eocene of Asia is too little known for any comparison with the California Eocene to have value.

The distribution of Upper Cretaceous fossils on the West Coast seems to conform to the climatic zones[1] as they existed in Africa and Europe, California and British Columbia having the central European type, while Lower California and Mexico have the equatorial type with *Hippurites* and *Buchiceras*.

After the Cretaceous, and indeed before the end of it, the faunas seem to have been limited closely to their present ranges.

SUMMARY.

From the foregoing pages the following conclusions are reached:

At the beginning of the Upper Devonian some widespread disturbance occurred, opening up connection between the American and Eurasian seas.

The Lower Carboniferous fauna of California was developed directly out of Devonian predecessors with the addition of some Eurasian elements by migration.

The Upper Carboniferous fauna was developed out of that of the Lower Carboniferous, but still with intermigration with the Russian and Asiatic regions, so that the California Carboniferous resembles the Eurasian even more than it does that of the eastern United States.

The Lower Triassic fauna of the West is entirely foreign, having migrated in from unknown regions, but having reached nearly simultaneously the western part of America, the Salt Range in India, and northern Siberia, but having been cut off from central Europe.

The Middle Trias of the West already begins to show relationships to the Mediterranean province of Europe, showing a connection in that direction, while the similarity to the faunas of the Arctic Trias province is disappearing.

In the Upper Trias the nearest faunal affinities are with the Himalayan and the Mediterranean provinces.

[1] M. NEUMAYR: Klimatische Zonen während Jura und Kreide Zeit.

In the Lower and Middle Jura there was no connection with European waters through the Pacific region, but rather through the Atlantic or "Central Mediterranean Sea" of Neumayr, bringing a central European fauna.

Near the beginning of the Upper Jura this connection with European waters was cut off, and one established with those of Siberia and northern Europe, bringing in a Boreal fauna.

This same connection was continued through part of the Lower Cretaceous, giving a Boreal fauna to the Knoxville.

Near the beginning of the Gault, connection with the Boreal sea of Russia was cut off, and communication established with southern India and through that country with central and southern Europe, bringing in a warm-water fauna. This connection existed during the greater part of the Cretaceous, but after this time the faunas are confined much more closely to their present ranges, although even today many of our living and Tertiary mollusca are found in Japan.

These changes in faunal geography are too widespread and easily correlated over great areas to be charged to mere mountain-making; they must rather be of the nature of continental uplift and subsidence. A study of these changes will throw light on the problem of the extinction of faunas and explain the great poverty of certain beds, in which the conditions for life seem favorable.

The fauna of California has not been a genetic series, but rather a succession of independent faunas, derived by migration from various parts of the earth, complicated by the mixture with the products of local development. Therefore the student that would intelligently study the genesis and history of this fauna must not neglect the fossil records of any region, since all may have contributed some elements to this complex assemblage of forms.

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THE AGE AND SUCCESSION OF THE IGNEOUS ROCKS OF THE SIERRA NEVADA.[1]

THE following notes and suggestions on the age of the igneous rocks of the Sierra Nevada are the outgrowth of field work in two parts of the range; one portion being a strip thirty miles wide across the mountains just south of the fortieth parallel, chiefly in the area of the Chico, Bidwell Bar and Downieville sheets of the United States Geological Survey; the other portion that part of the range to the south of Cosumnes River, or approximately latitude 38° 30′ N. The succession has been made out only partially and for only certain districts, and the article should therefore be considered merely as a contribution to the subject which must be later revised, and can be fully treated of only after more field work and a more thorough study of the material now on hand.

Mr. Waldemar Lindgren has acquired a large amount of information concerning the district across the central part of the range from Sacramento to Lake Tahoe, the geological maps of which have been prepared under his direction, and much light may be expected when his results are published. The writer is indebted to Mr. Lindgren for friendly criticisms.

The Sierra Nevada as a topographic unit may be described, following Whitney,[2] as the mountain area lying to the east of the Great Valley of California and to the west of the Great Basin, extending from near the Tejon Pass at the south end of the Great Valley to Lassen Peak on the north. As thus defined, the

[1] Published by permission of the Director of the U. S. Geological survey.

The chemical analyses given in this paper, unless otherwise stated, have been made by Dr. W. F. Hillebrand of the U. S. Geological Survey, whose high standing as an analyst is well known.

[2] Auriferous Gravels of the Sierra Nevada, p. 7.

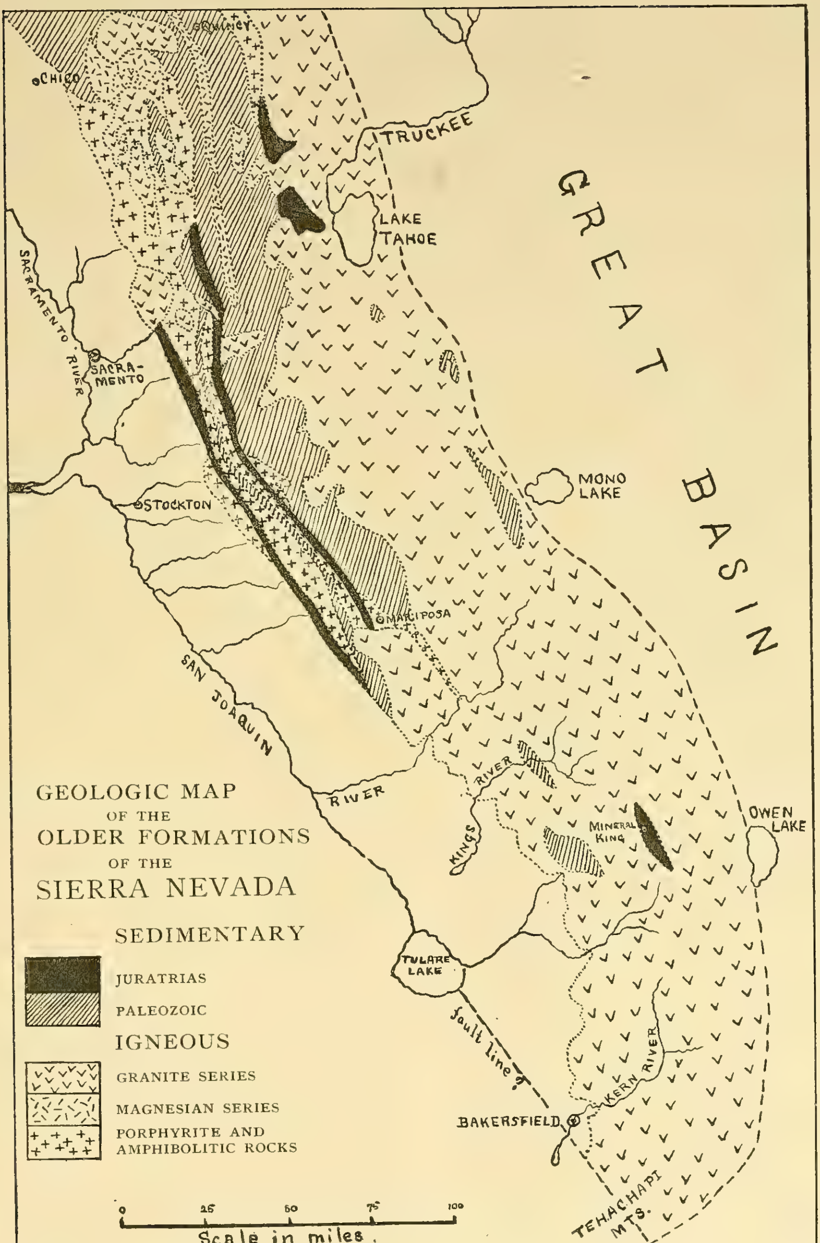
range lies wholly in the state of California, except the high granite spur lying just east of Lake Tahoe. Diller[1] has suggested, however, on geological grounds, that the range be limited on the north by the lavas of the Lassen Peak region, in the neighborhood of the North Fork of the Feather River, for to the north of this line there existed during Cretaceous time a great depression, which late in the Tertiary was filled in by the lava flows of Lassen Peak, which Diller considers as geologically related to the Cascade Range.

A little to the west of the Tejon Pass, according to Whitney,[2] "we pass at once from undisturbed Tertiary to strata of the same age, which are elevated at a high angle, and in so doing we leave the system of the Sierra and pass to that of the Coast Ranges." In a previous paper[3] the writer suggested that this line, separating little disturbed and highly disturbed beds, probably represents a line of faulting, the continuation of which further north is apparently followed by the San Joaquin and Sacramento Rivers. As is well known, the upper Cretaceous and Tertiary strata to the east of these rivers in the Sierra Nevada lie nearly horizontal, while to the west of it they are at nearly all points deformed. Adopting Diller's restriction of the range at its north end, the Sierra Nevada may be considered as terminating on the north, a little to the north of the North Fork of the Feather River; on the east at the west edge of the Great Basin; on the south at the Mojave Desert; and on the west at the hypothetical line of faulting above indicated. The eastern part of the Tehachapi Mountains will thus fall in the Sierra Nevada system. The geologic map (Plate VII) shows the range as thus restricted, the broken lines on the east and south being the line separating the Sierra Nevada from the Great Basin and the Mojave Desert. That portion of this line between Owen and Mono Lakes, and the portion east of Lake Tahoe coincide with a probable line of faulting, along which the Sierra has been elevated or the Great

[1] Eighth Annual Report, U. S. Geol. Surv., p. 404 and Plate XLV.

[2] Geol. Cal., Vol. I., p. 167.

[3] American Geologist, Vol. XIII., p. 248.


GEOLOGIC MAP
OF THE
OLDER FORMATIONS
OF THE
SIERRA NEVADA
SEDIMENTARY
JURATRIAS
PALEOZOIC
IGNEOUS
GRANITE SERIES
MAGNESIAN SERIES
PORPHYRITE AND AMPHIBOLITIC ROCKS
0
25
50
75
100
Scale in miles.
GREAT BASIN
CHICO
QUINCY
TRUCKEE
LAKE TAHOE
SACRAMENTO RIVER
SACRAMENTO
STOCKTON
MONO LAKE
MARIPOSA
SAN JOAQUIN RIVER
KINGS RIVER
MINERAL KING
OWEN LAKE
TULARE LAKE
fault line
KERN RIVER
BAKERSFIELD
TEHACHAPI MTS.

Basin depressed (or perhaps movements in both directions have occurred) in Tertiary time.

The Sierra Nevada, as thus outlined, appears to constitute a block of the earth's crust that has been practically rigid since middle Cretaceous time, although it has since, in common with most of California, experienced a considerable elevation, and there has been displacement by normal faults within the mass, particularly in Plumas county, at the north end of the range.

In another respect also the Sierra may be considered a geologic unit. The Tertiary lavas throughout the mass that have the widest distribution are very similar at distant points, and unlike Tertiary lavas in other adjacent areas, especially as to their form of occurrence and their relation in time. Thus the oldest flows of large extent were of rhyolite, succeeded by hornblende-pyroxene-andesite, chiefly in the form of tuff and breccia. This relation does not appear to hold good in the Lassen Peak region or in the Great Basin. The sediments of which the Sierra Nevada are in part composed are presumed to have been derived chiefly from an Archean land mass lying west of the central part of the state of Nevada, although it is by no means impossible that an Archean land area once existed on the site of the present Coast Range, and in that case part of the sediments may have been derived from the West. It is probable that there are within the Sierra Nevada formations ranging in age from Archean or Algonkian to Recent. Excepting, however, some Silurian fossils at the north end of the range, no evidence has thus far been found of rocks older than the Carboniferous, although in the northwest extension of the Auriferous Slate series of the Sierra Nevada in Siskiyou and Shasta counties, Diller and Fairbanks have collected Devonian fossils. On the geologic map (Plate VII.) only the older formations, constituting the Auriferous Slate series with the associated igneous rocks, are represented. On this map the Palæozoic corresponds with the Calaveras formation of the Gold Belt maps; the two narrow belts of Jura-Trias, on the west slope of the range, are the Mariposa beds; the Jura-Trias beds northwest of Lake Tahoe are the Sailor-Canyon and

Milton series, and the area in the southern part of the Sierra at Mineral King is probably Triassic in age. Under granite, which forms much the larger part of the range, are included the potash-poor granite or granodiorite of Becker, or tonalite of Vom Rath, and the porphyritic granite,[1] described in the Fourteenth Annual Report, United States Geological Survey. Nearly all the small areas noted on the map enclosed in schists or in basic igneous rocks are granodiorite, the porphyritic granite occurring chiefly along the crest of the range, especially in its southern part. The Magnesian series comprises serpentine, talc and tremolite schists with some other associated amphibolitic schists, the entire series being derived from basic igneous rocks. The porphyrites and amphibolitic rocks comprise the rocks laid down on the Gold Belt maps as diabase and porphyrite and amphibolite-schist derived therefrom, and altered igneous rocks which are now diorites, and which may be designated, following Cross, metadiorites, that is to say, diorites formed from other rocks by metamorphism without reference to the character of the original rocks. The material first determined by Wadsworth[2] as diabase-tufa forms a part of this series. There is, however, very little true diabase in the range, while porphyrites (altered andesites) on the other hand are abundant. The bisilicate that is most common in the porphyrite is augite, but large masses contain augite in very subordinate amount. Certain very basic portions of these areas seem to have contained olivine and are probably melaphyres. The silica contents of the series ranges from 48.86 per cent. in the melaphyre-like rocks to 68.56 per cent. in the porphyrites with metasilicates in small amount, and in some areas the acid porphyries grade over into still more acid varieties containing free quartz, as in the rocks of the Gopher Ridge. (See Jackson geologic folio.) The amphibolitic schists included within the porphyrite and amphibolite areas were

[1] This porphyritic granite was wrongly designated a granite-porphyry in the Fourteenth Annual Report, U. S. Geological Survey and in the American Geologist, Vol. XIII., p. 305. A similar use of the term may however be found in Hatch's Petrology, 1892, p. 114.

[2] Auriferous Gravels, p. 44.

formed from the porphyrites, melaphyres, etc., by dynamometamorphism. So generally have all these rocks been compressed that few outcrops can be found which do not show a rough schistosity. Let us add that the structure of these porphyrites and melaphyres is so obscured by secondary minerals (uralite, epidote, chlorite, zoisite and calcite) that it is little to be wondered that their true nature has not been clearly understood. It is now plain that the chief part of the rocks laid down on the geologic map as porphyrite and amphibolite schist are altered forms of original surface lavas and tuffs corresponding to modern basalts and andesites.

As has been stated before, the oldest known rocks in the Sierra Nevada, south of the fortieth parallel, are of Carboniferous age, and in treating of the history of the volcanic phenomena of the range we will commence with that period.

In the foothills of Eldorado, Amador, and Calaveras counties (see Placerville and Jackson folios) there is a narrow belt of clay-slate in which are numerous limestone croppings, and in several of these Carboniferous fossils have been found. Interbedded with the slate and limestone at several points are layers of conglomerate, composed of well-rounded pebbles. One of these layers is exposed by the road to Plymouth, in Amador county, northwest of Sugar Loaf, and at other points, and there is another similar one (possibly the same horizon) about three miles northwest of Golden Gate Mountain in Calaveras county. It is to be presumed that these conglomerates are of the age of the enclosing rocks, and in that case the pebbles they contain indicate with certainty the kind of rocks that existed before the Carboniferous or during an earlier portion of that period. The pebbles are largely of igneous rocks, although quartzite pebbles are present. The igneous pebbles are chiefly hornblende and mica porphyrites, but holocrystalline rocks, with idiomorphic augite, plagioclase, and leucoxene enclosed in orthoclase are also represented. The leucoxene appears to have formed from ilmenite. The plagioclase is mostly decomposed, as is also part of the augite. The orthoclase is largely fresh. The last-men-

tioned pebbles may be called augite-syenite. A partial analysis of one of them (No. 30 Amador county) by Dr. Stokes of the United States Geological Survey, gave the following results:

	No. 30 Amador.	165 S. N.
SiO_2	55.45	55.04
MgO	4.11	3.41
K_2O	5.18	1.41
N_2O	1.73	4.27

A rock in place closely resembling these pebbles has been found near Nevada City, by W. Lindgren, and is shown on his Grass Valley sheet in the Nevada City folio. To the north of Tehuantepec Valley in the area of the Downieville atlas sheet is a large mass of granitoid rock that has very nearly the same mineral composition and structure as the pebble above described. An analysis by Dr. Stokes of a specimen from this area is given above (No. 165 S. N.). This rock is composed of plagioclase, augite, rhombic pyroxene, iron ore, and brown mica enclosed in later unstriated feldspar that appears to be orthoclase, although the chemical analysis does not show enough potassa for much orthoclase to be present. The augite is plainly later than the plagioclases in places indicating a tendency to ophitic structure. There is a little quartz in the rock. All the constituents are fresh.

In the area of the Placerville sheet in southern Eldorado county, in the same belt of Carboniferous rocks noted above as containing conglomerate, there are numerous areas of igneous material. One of these, forming the hill known as Big Sugar Loaf, is a boss of porphyrite containing quartz and hornblende phenocrysts, and extending from this mass north across Slate Creek is a narrow dike containing abundant primary brown hornblende needles. This porphyrite boss is believed to represent an eruption of Carboniferous time. About three and a half miles north of Big Sugar Loaf is a hornblende-porphyrite area, and thin sections of the rock show a devitrified groundmass exhibiting flow structure. It is possible, however, to regard these masses as intrusive and younger than the enclosing slates, but

other elongated areas called diabase and porphyrite (db), on the Placerville map in the vicinity of these hornblende-porphyrite areas, are distinct tuffs and volcanic agglomerates, and there can be no reasonable doubt that the igneous fragments they contain were derived from volcanoes existing at the time the beds were forming. As hornblendic and augitic porphyrite fragments are very common in the agglomerates, we may safely assume that eruptions of porphyrite (old andesite) took place in the Carboniferous time in the foothill region. Exactly similar evidence is presented in the same belt of Carboniferous rocks in the area of the Jackson sheet. There are numerous streaks of fragmental porphyrites that are interbedded with the slates and evidently contemporaneous with them. In mapping these fragmental areas, the writer in places found much difficulty in deciding whether to lay down certain masses as pyroclastic rocks or as ordinary sediments, for there is a gradation from one to the other in places. The rule followed was to regard those layers as igneous that were chiefly composed of igneous fragments.

The most positive evidence of volcanic eruptions during the Carboniferous period has been brought forward by Diller,[1] who described a bed of tuff near Genesee Valley at the north end of the range in which Upper Carboniferous fossils were found. Mr. T. W. Stanton kindly collected a specimen of this tuff for the writer, on one side of which are shell impressions. A thin section shows numerous plagioclase phenocrysts and some non-twinned feldspars, probably orthoclase, in an altered groundmass containing very abundant minute fibers of a brightly polarizing secondary mineral, perhaps uralite. A partial analysis of this rock (No. 80 S. N.) made by Augustus Wedderburn under the direction of Professor Chas. E. Munroe, of the Columbian University, shows 5.01 per cent. of potassa, and 1.94 per cent. of soda. It is probably a trachyte.

The fossiliferous Upper Carboniferous beds on Little Grizzly Creek[2] are interbedded with porphyritic volcanic material more

[1] Bulletin Geological Society America, Vol. III., p. 374.

[2] American Geologist, Vol. XIII., p. 230, and Fourteenth Annual Report, U. S. Geological Survey, p. 448.

or less similar to that of the Robinson beds near Genesee Valley, but the rock in which the fossils occur is not itself a distinct tuff. It is composed of minute grains, probably of both quartz and feldspar, with abundant secondary greenish brown mica in minute irregular foils and green hornblende in slender fibers. The porphyritic feldspars in the tuff (No. 219, Plumas county) found just north of the Little Grizzly Creek fossil beds, and with little doubt part of the same series, appear to be largely orthoclase. Another similar tuff from an area farther south (No. 352) contains likewise large feldspars, some of them three-tenths of an inch in diameter. These are in part microcline. The same greenish brown mica found at the two other localities above described is also present in the groundmass. This and the greenish hornblende is probably the result of contact-metamorphism as granite occurs near each. A partial analysis by George Steiger, of No. 352, shows it to have approximately the composition of a trachyte.[1] Following the Carboniferous comes the Trias. Beds of this age have been found at Mineral King, at Genesee Valley and on Rush Creek. At the latter locality is a bed of conglomerate interstratified with slate and limestone, the latter containing pentagonal crinoid stems. This conglomerate was first discovered by J. E. Mills[2] and was visited by the writer in company with Mr. Diller. The pebbles of this conglomerate are well rounded, and may have been derived from land areas composed of Palæozoic rocks. Igneous pebbles are very abundant. These consist chiefly of quartz-diorites that seem originally to have been quartz-gabbros, the pyroxene now being hornblende. One pebble is chiefly made up of hornblende derived from pyroxene with a few spots of secondary material containing aggregates of minute, black particles, representing possibly original olivine, in which case this rock was a lherzolite. This pebble may have been derived from the large area now largely serpentine that forms Red Hill, just west of Rush Creek. Mr. Mills in his bulletin states that he found pebbles of granite like that forming Spanish Peak, but he

[1] Fourteenth Annual Report, U. S. Geological Survey, p. 448.

[2] Bulletin Geological Society, Vol. III., p. 429.

does not appear to have had the specimens examined microscopically. Neither Mr. Diller nor the writer found any pebbles of the Spanish Peak rock (a quartz-mica-diorite) in the conglomerate. The southern extension of the Red Hill serpentine area is shown on the geologic map a little west of Quincy.

The long belts of porphyrite and amphibolite indicated on the map on either side of the narrow belt of Palæozoic (in this case certainly Carboniferous) rocks are very probably Jura-Trias in age. In fact, certain portions are without doubt of Jurassic age. A section across the Bear Mountains, which lie east of Stockton, shows the relation of the igneous and sedimentary formations.

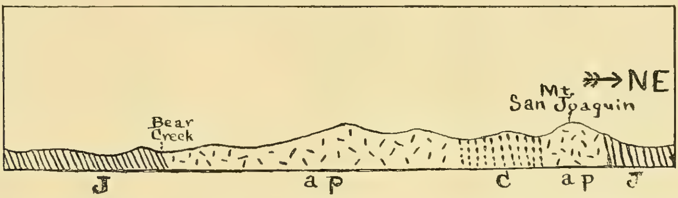


FIG. 1. Section across the Bear Mountains, extending vertically to sea-level. C.—Carboniferous slates. J.—Jurassic slates. ap.—Porphyrite, porphyrite tuffs, and amphibolite. Vertical and horizontal scale two miles to the inch.

We have here a central belt of Carboniferous slates flanked on either side by augitic porphyrites and tuffs, and at both the east and west base of the Bear Mountains are Jurassic slates, which have been designated the Mariposa formation. The porphyrites and their tuffs being surface formations, there seems good ground for regarding them as products of volcanoes that existed after the Carboniferous and before the close of the Jurassic. It may also be assumed that the portions of each porphyrite belt lying nearest the Carboniferous slates are the oldest. The tuffs along the east borders of the eastern area merge into the Jurassic slates, the latter containing frequent layers of the augite-tuff, so that it is difficult on the east slope of the Bear Mountains to draw an exact line between the tuff and the slates. There can be no doubt as to the age of these tuff layers, for in some of them ammonites have been found. The one found nearest the line of the section came from a branch of Cherokee Creek at the

east base of the Bear Mountains, and occurs in an augitic slate.[1] In the collection of Stanford University there are two specimens of ammonites from the same horizon as the Cherokee Creek specimen, although the localities are further north on the area of the Placerville sheet. The rock in which the fossils occur is a distinct augite-porphyrite tuff, and would ordinarily be called greenstone. The writer is indebted to Professor J. P. Smith for the following information concerning them: One ammonite is *Perisphinctes* conf. *colfaxi* Gabb sp., and was found by Mrs. M. J. Gates at Huse's bridge over the Cosumnes river; the other is *Perisphinctes* sp. or *Olcostephanus*, and was found in a bowlder near Nashville, Eldorado county, by J. C. Heald. Both species indicate the Upper Jura.

According to Diller,[2] the Hinchman tuff at Mt. Jura in Plumas county contains lapilli, affording evidence in that section of volcanoes during the time of deposition of the tuff (Upper Jura). Mt. Jura is perhaps one of the best places in the range for the chronological study of ancient volcanic materials, both on account of the greater freshness of the rocks and the abundance of fossils.

As will be noted on the geologic map, the large area of porphyrite and amphibolite widens going north. On the Smartsville geologic map, now being published, these rocks may be seen to occupy a large portion of the surface of the country. They have been studied mostly by Mr. W. Lindgren, who agrees with the writer in regarding them as chiefly surface eruptions and probably Jura-Trias in age. These rocks, largely augite-porphyrites and their tuffs, are presumed to have covered, as with a mantle, the underlying Palæozoic formations. There are some streaks of slates among the eruptive masses, but these have not in the Smartsville area afforded any fossils. However, during the past season, in the north extension of the same area, in a belt of clay-slate interbedded with augite-breccia and tuff, fossil plants were collected by T. W. Stanton. The exact locality is by the stage

[1] Fourteenth Annual Report U. S. Geological Survey, p. 453.

[2] Bull. Geol. Soc. Am., Vol. III., p. 373.

road south of the Oroville Table mountain, near the Banner gold quartz mine. Professor Ward examined these plant remains and expressed the opinion that they are of middle Mesozoic age, and then referred them to Professor Fontaine, whose report is herewith appended:

[*Extract from letter of Professor Wm. M. Fontaine to Professor Lester F. Ward, dated April 22, 1895.*]

I have examined carefully the plants from near Oroville, Cal., collected by Stanton and Oliver, with the following results:

1. Perhaps the most common form is a *Tæniopteris*, which I cannot distinguish from *T. stenoneura*, Schenk, found in the Grenzschichten and in the lower Rhetic of France.

2. Not uncommon is a narrow form which is most probably *Tæniopteris tenuinervis* of the same beds, and which is still more characteristic of the Rhetic.

These narrow Tæniopteris forms are the most abundant imprints among the California fossils. This type goes up, it is true, as far as the Oolite, but in species not seen among these fossils. Macrotæniopteris, if present, must be much rarer than Tæniopteris. I am not sure that any of this type is present. There is one large fragment, poorly preserved, that looks much like a Macrotæniopteris, which resembles *M. magnifolia*. There is a ribbed imprint, an imprint of the inner wall of either an Equisetum or Schizoneura. It looks more like the imprint Schenk calls *Calamites Gumbeli* of the Grensch, which Schimper makes *Equisetum Gumbeli*. There is a very fine plant of *Ctenophyllum grandifolium* of the Richmond coal field, and several fragments of the same plant. This is of great value in fixing the age of the strata, as this type of plant is unmistakable, and is not known except in the uppermost Trias and Rhetic. Schenk's *Pterophyllum carnallianum* is probably a small variety of it. I may say here that a few years ago some Mexican brought a few fossil plants from Mexico, and they were submitted to me. Among them were fine specimens of this Ctenophyllum, and from them I felt sure that uppermost Trias and Rhetic extend into Mexico.

There are several good imprints of a Podozamites which I cannot distinguish from *P. Emmonsi* of the N. C. uppermost Trias. Possibly it may be *P. lanceolatus*. If so, it is the Rhetic rather than the Jurassic type of this widely extended and persistent form of Podozamites. It is now so much expanded by species-makers that it is rather a group-type than a species, like *Pecopteris Whitbiensis*.

There are a number of scattered leaves like Schenk's *Zamites angustifolius* or more probably *Podozamites tenuistrictus* of the Richmond coal.

There is an imperfectly preserved imprint of a very large Danæopsis,

probably *Danæopsis marantacea*, another Rhetic plant. It shows the nervation and basal portion of several pinnules attached to the rachis.

There are probably three different ferns, but they are so few and in such small fragments of the terminal portions of ultimate pinnæ, that nothing of their true nature can be made out. It is impossible to say if they are Triassic or Jurassic. They have rather more of a Jurassic than a Triassic facies.

Taking all the evidence, I think it can be positively said that *this flora is not older than the uppermost Trias, and not younger than the Oolite.* I feel pretty sure that it is true Rhetic, somewhat younger than the Los Bronces flora of Newberry, and the Virginia Mesozoic coal strata. It is much like the Rhetic flora of France, made known by Saporta. At any rate, this *is a new grouping of plants that certainly deserves to be carefully collected. I do not think the fossils now in hand suffice to fix narrowly the age, which may be lower Jurassic.*

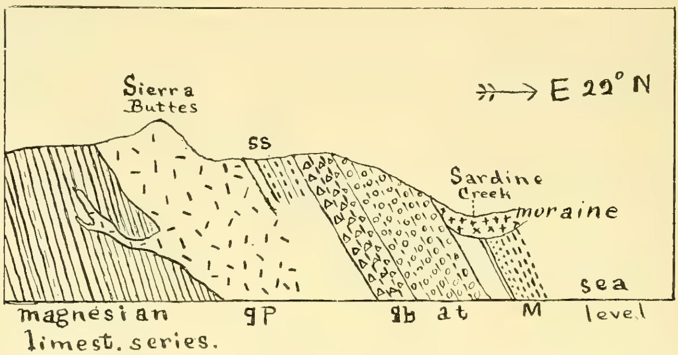


FIG. 2. Section across the Sierra Buttes. Horizontal and vertical scale one mile to the inch. qp=quartz-porphyry. qb=quartz-porphyry breccia. at=augitic tuffs. M=Milton series. ss=siliceous schist.

On the east slope of the Sierra Buttes (Downieville atlas sheet) the rocks are magnificently exposed through glacial agency, and during the past season the writer obtained evidence there of the succession (see Fig. 2) of the old volcanic rocks which form the larger part of the Buttes.

Forming the mass of the Buttes is a fine-grained rock containing abundant porphyritic quartzes. No analysis has been made of the Sierra Buttes rock, but from the north end of the same area, which extends to Eureka Peak, three specimens were collected and analyzed,[1] giving the following results :

[1] Fourteenth An. Rep. U. S. Geol. Survey, p. 473.

Silica	73.62	per cent.	to	79.41	per cent.
Lime	.09	"	"	2.55	"	"
Potassa	2.23	"	"	4.27	"	"
Soda	2.46	"	"	3.78	"	"

As there is some carbonate in minute particles in these rocks, it is quite likely that in the fresh rock the lime never reaches as small a quantity as .09 per cent. Although containing too much lime and too little potassa for a typical quartz-porphyry, the variation is not sufficient to exclude the rock from the quartz-porphyry group, and it will be so called here.[1]

Overlying the quartz-porphyry is a sedimentary lens, partly a dark siliceous schist and partly coarser material, dipping easterly at angles of from 50° to 60°. In this lens is the quartz vein of the Mountain mine. At one point in the sedimentary mass is a layer of quartz-porphyry about 50 feet thick which may be an intruded sheet or a contemporaneous flow. Radiolarian-like remains were noted in the sections of a dark, fine-grained breccia that forms part of this clastic series. This sedimentary mass has been designated a "lens" since it feathers out both to the north and south. Other lenses, usually entirely made up of dark siliceous schist and slate, occur in the Sierra Buttes, from one of which at the Phœnix mine an ammonite was collected.[2] Some of these lenses are entirely enclosed in the quartz-porphyry, and it is probable that the entire series, the quartz-porphyry as well as the overlying formations, is Jura-Trias in age.

Superimposed with apparent conformity on the clastic series just described is a breccia containing abundant angular microlitic fragments and angular quartzes which are in part idiomorphic. This series is designated in the section a quartz-porphyry breccia, overlying which is a huge bed of altered augitic pyroclastic rock without free quartz. Moraine material covers the lower part of the slope, but one mile further south in the bed of the North Fork of the North Fork of the Yuba River, this augitic tuff is

[1] Cross gives analyses of two quartz-porphyries from Leadville that contain very similar silica, lime and alkali ratios to those given above. Monograph XII., U. S. Geol. Survey, p. 326.

[2] Am. Geol., Vol. XIII., p. 232.

plainly seen to be conformably overlain by the red slates and fine-grained tuffs of the Milton series. Near Milton, there is good evidence that this last series is unconformable on the Palæozoic rocks to the west. These Palæozoic rocks are called in the section the magnesian-limestone series, there being in it frequent irregular masses of magnesian limestone, but no fossils have been found in any portion of it, and it is presumed to be Palæozoic in age on account of the highly metamorphosed condition of most of the material composing it. There are dikes of quartz-porphyry in the magnesian-limestone series. The dip of the pyroclastic and clastic rocks overlying the quartz-porphyry of the Sierra Buttes is to the east at angles varying from 50° to 60°. The dip of the Palæozoic rocks to the west is often vertical, but dips to the east at high angles have been noted at many points. While these dips represent in part the dip of the original stratification, at some points they probably indicate the dip of the schistosity.

To the east of the Milton series is a large granite mass which appears to be of later age, since the Milton rocks show evidence of contact metamorphism.

There are then at the Sierra Buttes an acid volcanic series (quartz-porphyry and quartz-porphyry-breccia), with an overlying augitic pyroclastic series more basic in composition, and later than the whole volcanic series, a deep-seated intrusive acid rock (granodiorite).

The succession of the effusive rocks, acid quartz-porphyries, and more basic augitic tuffs, is strikingly similar to the succession of the Tertiary effusives, rhyolites and andesites, described hereafter.

In addition to the above rocks, there are in the same region numerous dikes cutting the various igneous formations. Thus the quartz-porphyry of Eureka Peak (same area as that of the Sierra Buttes) is cut by dikes of an altered rock that appears to be an aplite (No. 150 Plumas), and also by a more basic rock, probably originally an augitic porphyrite (Nos. 385 and 386 Plumas), but the idiomorphic phenocrysts of this are now

fibrous hornblende. On the southwest slope of Mt. Elwell, the augitic tuffs that overlie the quartz-porphyry series are cut by a dike of a white rock (No. 108 Plumas) of a fine-grained granular structure, and composed of quartz and feldspar with smaller amounts of secondary epidote and fibrous hornblende. The rock is thought to be an aplite. The same augitic tuff series at a point about one and three-fourth miles southeast of Mt. Elwell is cut by a dike of hornblende-porphyrite (No. 206 Sierra county). Forming the east base of Eureka Peak is a dark, coarse, granular rock which is seen under the microscope to be a gabbro. The contact of this rock with the quartz-porphyry is sharp, and as there are angular fragments of the gabbro enclosed in the porphyry, it appears that the gabbro is the older rock. At a point eight-tenths of a mile (No. 133 Plumas), and at another point one and three-fourths miles southeast of Eureka Peak, there are in this gabbro white dikes that microscopically appear to be aplites. Cutting No. 135 is a darker colored dike (No. 136) which contains outlines of squarish crystals, one showing truncated corners, presumably originally augite (but now replaced by calcite, epidote, quartz and chlorite), in a microlitic feldspar groundmass. In a ravine on the northeast slope of Eureka Peak enclosed in the quartz-porphyry there are fragments of a rock weathering reddish (No. 383 Plumas). On microscopic examination these proved to be apparently quartz-diabase, identical in structure with the rock (No. 550 Calaveras) that occurs as a dike in the granitoid quartz-porphyry southeast of Milton near Rock Creek (Jackson atlas sheet). The rock is ophitic in structure, the divergent plagioclases penetrating the quartz grains as well as the chlorite and epidote which seem to represent original augite. In No. 550, the metasilicate is chiefly hornblende, which is presumed also to have been augite. In addition there are numerous grains of iron ore. This peculiar ophitic rock has thus far been noted by the writer only at the two points above mentioned. As the rock needs more investigation, it will not be further considered here.

Six and seven-tenths miles southeast of the Sierra Buttes in

he granite (granodiorite) is a dike of augite-porphyrite (No. 226 S. N.) in which the augite is largely altered to fibrous green hornblende which is grouped in radiating brushes. Some of the augites are unaltered at the center with a rim of the coarsely fibrous hornblende. If there was olivine in the rock, it is now completely gone. The rock is dark green in color, strongly resembling the rock that forms a small area on the summit of the highest of the Sierra Buttes, and this latter rock appears to have contained olivine and would then be a melaphyre. Along the augite-porphyrite dike (No. 226 S. N.) is a white dike (No. 227 S. N.) about two feet wide which thus occurs between the augite-porphyrite and the granite. This rock appears to be a micropegmatitic form of aplite. The time relation of the augite-porphyrite and the aplite was not ascertained.

Chemical analyses of the dikes have not been made, but if the writer is correct in his determination of these altered rocks, we have the following succession in the Eureka Peak–Sierra Buttes region.

MEDIUM BASIC -	Gabbro — Boss.	
ACID - - - -	Quartz-porphyry — effusive, large sheet.	
MEDIUM BASIC -	Augite porphyrite — effusive, mostly tuff, large sheet.	
ACID - - - -	Granite (granodiorite).	Intrusive.
ACID - - - -	Aplite.	
BASIC - - - -	Augite-porphyrite (?) or melaphyre (?)	
MEDIUM BASIC (?)	Hornblende-porphyrite.	

The relative age of the aplite, late augite-porphyrite, and hornblende-porphyrite yet remains in doubt, the only evidence being that the greenish dike (No. 136), apparently an augite-porphyrite, cuts the aplitic dike (No. 133).

In the area of the Jackson sheet are a number of bodies of rock that are designated on the geologic map of that area as quartz-porphyrite. Analyses[1] of these rocks, however, show them to have a composition very similar to the quartz-porphyry of the Sierra Buttes. The quartz-porphyrites should perhaps be restricted to altered andesitic rocks with free quartz, and with less than 70 per cent. of silica, corresponding to modern dacites.

[1] Fourteenth An. Rep. U. S. Geol. Survey, p. 484.

If this rule be followed, all of the quartz-porphyrites of the Jackson geologic map should be called quartz-porphyries. The following analyses, however, show that the lime and alkali ratios are very similar in the Jackson sheet quartz porphyries, and in typical dacites, so that in reality they constitute a group intermediate between typical quartz-porphyries and typical quartz-porphyrites.

	Dacites				Quartz-Porphyries		
	129	131	A	B	151	553	549
SiO - - - -	65.66	67.49	69.51	68.20	70.29	71.19	72.24
CaO - - - -	3.64	2.68	1.71	4.33	2.30	2.87	3.40
K_2O - - - -	2.03	2.40	3.34	1.52	3.05	1.82	.39
N_2O - - - -	3.65	4.37	3.89	2.98	2.68	4.24	4.43

Dacites 129 and 131 are from Sepulchre Mountain,[1] and the two designated as A and B are from Lassen Peak, Cal.[2]

Nos. 151, 553 and 549 are from the area of the Jackson sheet.

These rocks with porphyritic quartzes seem usually to be intrusive in more basic igneous rocks, augitic porphyrites and amphibolite-schist. An exception to this rule is the rock of the south part of the Gopher Ridge, south of the Salt Spring Valley reservoir. This grades over into a porphyrite containing augite, and is probably older than quartz-porphyries 553 and 549 which occur at the west base of the range, and are almost certainly intrusive, and, as no analysis has been made of it, it should perhaps be properly called a quartz-porphyrite and not a quartz-porphyry, on the basis above stated.

Intrusive in the augite-porphyrite and tuff that forms the western ridge of the Bear Mountains is a dike of serpentine, originally a peridotite or pyroxenite.

We have then in the Jackson sheet area:

Intermediate -	Augitic porphyrites — Effusive.
Basic - - - -	Peridotite — Intrusive.
Acid - - - -	Quartz-porphyry — Intrusive.

[1] Thirteenth An. Rep. U. S. Geol. Survey, p. 648.

[2] Bull. No. 9, U. S. Geol. Survey, p. 16.

The time relation of the peridotite and quartz-porphyry is not known to the writer.

At the south end of the Gold Belt in Mariposa county there is a very interesting series of igneous rocks, the oldest of which appear to be augite-porphyrites and their tuffs, and their dynamometamorphic derivatives, some of which may be Palæozoic, and others Jura-Trias in age. They in no way differ from similar rocks that have been described above from the Jackson sheet area and elsewhere. These surface augitic volcanics are interbedded with schists and slates, and the entire series is cut off and metamorphosed by the granite a little south of the town of Mariposa (see Plate VII.) About Cathey Valley and westward from there to Hornitos are considerable areas of a dark granular rock some of which is seen under the microscope to be typical diabase with ophitic structure. In portions of the area the augite is replaced by brown hornblende, and the rock is then an ophitic diorite. No. 446, Sierra Nevada collection, probably represents nearly the average composition of this diabase. This specimen is from a dike by the road northeast of Hornitos. It is composed of augite and hornblende apparently intergrown, in which are imbedded feldspar laths. The area about Cathey Valley forms much the largest area of true diabase known to the writer in the Sierra Nevada. As the rock occurs in dikes in the greenstone tuffs and schists (augitic tuffs and their derivatives), it is evidently younger than at least a portion of the greenstone series.

Forming the high ridge east of Cathey Valley, and abutting against the coarser hornblendic granite that cuts off the slate series south of Mariposa, is a fine-grained granite in places practically an aplite. This fine-grained granite may be but a modification of the coarser granite, but is thought to be later. Ferro-magnesian constituents are rare in the larger part of the area, much of which may be called a soda-aplite (see analysis No. 413). Analysis No. 369 is of the coarser granite, from the Chowchilla River, and from the west edge of the same granite mass that cuts off the Mariposa slates west of the town of Mariposa, metamor-

ANALYSES OF PRE-TERTIARY IGNEOUS ROCKS.

SPECIMEN NUMBER.	PORPHYRITE.	AUGITIC TUFF.	MELAPHYRE?	PERIDOTITE.	DIABASE.	QUARTZ-MICA-DIORITES (GRANODIORITES).			HBL.-MICA POYPHYRITE.	PORPHYRITIC GRANODIORITE.	APLITES.		DIORITE (?)
	25 S. N.	19 S. N.	26 S. N.	325 S. N.	446 S. N.	71 S. N.	303 S. N.	369 S. N.	304 S. N.	39 S. N.	413 S. N.	161 S. N.	250 Butte.
SiO_2	68.58	54.66	49.24	44.81	51.32	67.33	68.65	62.62	66.65	66.28	74.21	76.03	57.87
TiO_2	.57	.67	.96	1.88	1.23	.36	.28	.55	.33	.54	.30	.07	.53
Al_2O_3	13.04	15.85	14.79		15.28	15.93	16.34	17.51	17.61	16.03	14.47	13.39	16.30
Cr_2O_3	..	..	..	.29	..	..	..	..	..	..	..	..	..
Fe_2O_3	.26	1.82	1.52	1.98	.47	1.90	.93	.49	.93	1.80	.35	.48	1.71
FeO	3.40	5.12	8.00	4.52	8.59	1.59	1.48	4.06	1.67	1.88	.50	.31	3.86
MnO	.15	.18	.18	.13	..	.09	.08	.05	.07	.05	none	trace	.08
NiO	..	..	..	.09	.16	..	..	..	..	..	..	..	..
CaO	3.22	8.75	10.74	6.58	11.58	4.09	3.07	5.49		3.75	1.71	1.28	5.53
SrO	strong trace	trace	trace	none	faint trace	trace	.07	trace	4.44	trace	trace	trace	trace
BaO	.10	.04	.04	none	none	.08	.09	trace	.12	.08	none	.04	.05
MgO	1.01	5.64	6.89	30.91	7.25	1.63	1.29	2.84	1.26	1.12	.28	.05	5.50
K_2O	1.90	*.47	.88	.15	.22	2.46	1.85	1.76	1.70	3.49	.10	5.18	.75
Na_2O	4.94	3.46	2.76		2.92	3.76	4.85	3.49	4.59	4.10	7.62	2.98	5.01
Li_2O	none	none	trace	..	faint trace	trace	trace	trace	trace	trace	trace	none	trace
H_2O below 110° C.	.16	.25	.20	.15	.06	.19	.24	.22	.03	.11	.15	.15	.26
H_2O above 110° C.	1.00	2.48	2.97	6.88	.95	.66	.62	.92	.41	.39	.23	.34	2.40
P_2O_5	.20	.15	.17	.02	.25	.11	.15	.12	.18	.30	.07	.03	.27
CO_2	1.31	.39	.90	1.79	..	..	..	..	..	..	..	..	..
FeS_2	.15	.09	..	..	..	..	..	..	..	..	..	..	..
	99.99	100.02	100.08	100.18	100.28	100.18	99.99	100.12	99.99	99.92	99.99	100.33	100.12

phosing them near the contact into mica and andalusite schists. In Yaqui Gulch some of the latter contain impressions of shells of *Aucella erringtoni*, Gabb, proving their upper Jurassic age. No. 399 is the fine-grained granite from Agua Fria Creek and not far from its contact with the coarse granite. Its mineral composition is not greatly different from that of the coarse granite as represented by No. 369. It is microscopically a micropegmatite with minute foils of brown mica gathered in groups. No. 413 is a white medium-grained rock, and a fair sample of the larger part of the area. It is composed of feldspar and some quartz plainly discernible as such, with a large amount of micropegmatite. In Cathey Valley and to the southeast of it, the diabase before described and the fine-grained soda-granite come in contact, forming a zone of contact-breccia in places more than a mile wide. The fragments of diabase are cemented together by white feldspathic material presumably from the granitic magma, indicating the later age of the white granite.

The augitic porphyrites of Mt. Bullion, north of Mariposa, are cut by a dike of serpentine, doubtless originally a peridotite.

Near Mormon Bar, south of Mariposa, is a dike of hornblende-porphyrite in the coarse granite.

The succession of the old igneous rocks in the Mariposa region is then, so far as made out, as follows:

Augite-porphyrite, chiefly tuff, effusive.	
Diabase, - - - - - - - - -	Intrusive.
Serpentine, - - - - - - - -	
Coarse granite (quartz-mica-diorite), - - -	
Fine-grained granite (aplite), - - - -	
Hornblende-porphyrite. - - - - -	

As bearing on the age of the hornblende-porphyrite, it might be stated that at many points the granite and other rocks are cut by dikes of a dark rock containing original hornblende, some occurrences of which are granular in structure and allied to diorite, and others have a distinct groundmass and are more correctly called hornblende-porphyrite. An analysis of one of these (No. 250 Butte county collection) is given in the table. This is apparently holocrystalline, but the feldspar between the

idiomorphic hornblendes has crystallized in ill-defined branching forms. In the feldspathic material there are numerous minute green dots that appear to be chlorite. The analysis corresponds closely to that of the augitic tuff (19 S. N.) and to the composition of some pyroxene-andesite except that soda is greatly in excess of potash.

There are abundant dikes of fine-grained white granites (aplites) in the coarse granite of the Sierra Nevada. These in general have very nearly the composition of typical granites. They contain, as a rule, very little mica or hornblende. An analysis of one of these dikes is given in the table (No. 161 Sierra Nevada collection). The specimen was taken two miles southeasterly from Deadman's Peak, in the area of the Downieville sheet. It will be observed that the rhyolites, Nos. 126 Amador and 365 Plumas, have practically the same chemical composition as the aplite.

The volcanoes of Jura-Trias time in the Sierra Nevada appear to have been much more active than those of Palæozoic time, judging from the evidence offered in the preceding pages, and from that exhibited by the maps of the Gold Belt now being issued.

Following the Jura-Trias there seems to have been a long period during which the volcanic action was quiescent. This period apparently comprised most of Cretaceous and Eocene time.

The main facts concerning the age and succession of the Tertiary lavas of the Sierra Nevada have already appeared in print,[1] and only a short statement will be here inserted, together with some additional information obtained lately.

The first Tertiary eruptions, the relative age of which is clear, occurred apparently in Miocene time. These consisted of flows of rhyolite, which filled many of the old river valleys, but do not appear to have covered the higher ridges. The Miocene age of

[1] Am. Jour Science, Vol. XLIV., pp. 455–459; Am. Geol., Vol. XI., pp. 309–316; and the Fourteenth An. Rep. of the Director U. S. Geol. Survey, pp. 493–495.

the rhyolite-flows is shown by the plant remains occurring chiefly in clay beds of the Neocene Auriferous gravels with which the rhyolitic material is associated. Some of these clays have been thought themselves to be decomposed rhyolitic material. These plant remains, chiefly leaves, have been studied by Lesquereux, Ward, and Knowlton. Professor Lesquereux, it is true,[1] first considered the plants from the Auriferous gravels to indicate a Pliocene age for the containing beds, but in a more recent report[2] he refers other plants from the same, or possibly a somewhat later horizon, to the Miocene.[3]

Analyses of two rhyolites are given in the table (Nos. 126 Amador county, and 365 Plumas county). A number of partial analyses have been made of rhyolites from other localities, and all show a remarkably uniform silica, lime, soda, and potash ratio.

In Butte and Plumas counties there are extensive tables of a dense fine-grained black basalt, represented in the table of analyses by No. 276 Plumas county, and No. 18 Sierra Nevada. At many points the tables of this basalt are capped with andesite-breccia, showing that it is earlier than the andesite. Its age relative to the rhyolite is not known to the writer, but it is thought to be later, since the gravels which it covers at some points appear to belong to later channels than those covered by the rhyolite. Still, at Sawpit, northwest of Onion Valley (Downieville atlas sheet), this older basalt covers the older white quartz gravels, and on the Oroville Table Mountain it caps the Ione formation.

After the rhyolite and older basalt flows there was a period of erosion before the main andesite eruptions. These were of hornblende-pyroxene-andesite, an analysis of an average sample of which is given in the table (No. 72 Sierra Nevada collection). Much of the andesite occurs in the form of a tuff or breccia, and

[1] Memoirs Museum of Comp. Zoöl., Vol. VI., No. 2, p. 54.

[2] J. S. DILLER, Eighth An. Rep. U. S. Geol. Survey, p. 419.

[3] The age of the Auriferous gravels is discussed in a paper by DILLER (JOURNAL GEOLOGY, Vol. II., pp. 32–54) and in a paper by the writer to appear in the American Geologist, June 1895.

ANALYSES OF TERTIARY IGNEOUS ROCKS.

SPECIMEN NUMBER.	Rhyolite.		Older Basalt.		Table Mt. Basalt.	Hbl.-pyr. Andesite.	Hbl.-Andesite.	Late Pyroxene-Andesites.					Qtz-Andesite.	Late Doleritic Basalt.	
	126 Amador	365 Plumas.	276 Plumas.	18 S. N.	36 S. N.	72 S. N.	16 S. N.	262 S. N.	1829 Cascade Range.	209 S. N.	661 S. N.	626 S. N.	311 Plumas.	314 Plumas.
SiO_2	73.23	71.39	50.56	50.66	56.19	58.47	60.20	59.34	68.12	66.94	56.90	60.02	53.91	52.81
TiO_2	.09	.17	1.71	2.39	.69	.51	.57	.32	.25	.30	..	.42	.52	.84
Al_2O_3	12.73	14.13	14.71	13.97	16.76	18.80	17.21	17.61	16.24	16.49	..	16.07	17.95	16.60
Cr_2O_3	..	..	..	..	..	..	..	..	none	..	..	trace	..	..
Fe_2O_3	.99	.63	3.54	2.55	3.05	3.34	3.12	3.63	1.26	1.41	..	2.17	2.21	2.66
FeO	.16	.37	8.90	10.20	4.18	2.64	2.69	2.28	2.08	1.87	..	3.46	4.80	6.13
MnO	trace	trace	.13	.29	.10	.13	.12	.12	.10	.13	..	.10	.10	undet.
NiO	..	..	..	trace	..	..	..	..	..	..	..	none	..	..
CaO	.61	1.01	7.58	8.08	6.53	6.60	6.04	6.45	3.80	4.77	7.83	7.01	10.40	10.14
SrO	none	trace	trace?	trace	strong trace	.05	trace	.04	.02	.05	..	trace	trace	trace
BaO	.02	.09	.25	.22	.19	.09	.11	.11	.09	.07	..	.08	.05	.03
MgO	.22	.08	4.07	4.45	3.79	2.69	3.18	3.50	1.35	1.98	..	4.57	5.52	6.12
K_2O	5.17	5.69	2.10	1.95	4.46	2.01	1.44	1.94	2.54	1.65	1.37	1.59	1.34	1.05
Na_2O	1.91	2.89	2.94	3.32	2.53	3.58	3.35	3.40	3.89	3.88	3.24	3.55	2.90	2.79
Li_2O	trace	trace	trace?	none	trace	trace	trace	trace	trace	trace	..	none	trace	trace
H_2O below 110° C.	.53	.42	1.06	.27	.34	.14	1.12	.64	..	.35	..	.24	.20	.38
H_2O above 110° C.	4.51	3.32	1.12	.43	.66	.92	1.18	.74	.40	.22	..	.45	.20	.54
P_2O_5	.02	.03	1.14	1.01	.55	.22	.17	.25	.14	.12	..	.17	.21	.23
SO_3	..	..	..	Cl..02	..	..	..	..	..	..	..	SO_3.06	..	..
	100.19	100.22	99.81	99.81	100.02	100.19	100.50	100.37	100.28	100.23	..	99.96	100.31	100.32

appears to have issued from fissures near the summit of the range, mixed with water, forming enormous mud flows which covered a large part of the western slope of the range. At Poker Flat (Downieville atlas sheet) Canyon Creek cuts across a huge fissure filled in part with rubble of the adjacent rocks, but chiefly with fragmental andesite. This was at first taken to be evidence that the mud flows became such before issuing from the inner regions, that is to say, the volcanic material was thought to have been broken and mixed with water within the earth. The creek has cut to a depth of 1000 feet or more through this fragmental dike, without reaching the bottom of it. During the past season, however, another similar occurrence was found, where it is plain that the fissure was filled from above. This second instance is about one and one-fourth miles south of Cammel Peak (Bidwell Bar atlas sheet), in the canyon of Fall River. The stream has cut into this second fragmental dike of andesite-breccia to the depth of about 500 feet, and in the dike material in the bed of the river are imbedded numerous fragments of fossil wood. These pieces of wood must have been washed into this fissure from the surface together with the andesitic material in which they are imbedded. The specimens of wood collected were referred to Professor F. H. Knowlton, who reports that "it is a *Sequoia* of the redwood, or *S. sempervirens* type. The wood is not well enough preserved to enable me to say that it is the same as the living redwood, although it is undoubtedly near it."

Fragmental volcanic rocks are usually supposed to have been formed by explosive action, the material being thrown out as fragments and ashes, which, falling on the surrounding land, or in bodies of water, would in the former case assume a roughly and in the latter a definitely stratified shape. But this does not seem to form an adequate picture of the Pliocene andesitic eruptions of the Sierra. As before stated, the fragmental andesite appears to have been mixed with water, perhaps derived from melting snow at or very near the sources of the eruption. But however these mud flows were formed, on their course down the slopes of the range they caught up much foreign material. Silici-

fied trunks of both deciduous and coniferous trees, bowlders of granite, some of them tons in weight, and pebbles and fragments of nearly all the older rocks of which the Sierra Nevada is composed, are found imbedded in the andesitic material.

Along the east side of the Great Valley of California these andesite-tuffs grade into well-stratified material containing abundant rolled sand grains, and such areas may be regarded as water deposits. A most remarkable fact has been noted by the writer in regard to these tuff areas, and that is that wherever the original top layer of the beds has been preserved this is, so far as observed, a distinct breccia, composed chiefly of angular fragments and blocks cemented by ashes, while below are layers of

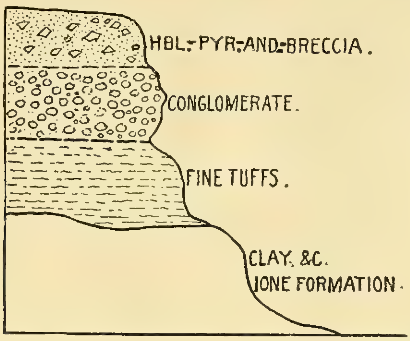


FIG. 3. Lava-capped hill four miles west of Ione. Elevation about 400 ft. above base.

fine tuff and volcanic conglomerates. The accompanying section (Fig. 3) represents the layers composing a flat-topped hill about four miles west of Ione, in Amador county.

With variations as to the layers of conglomerate and tuffs in their number and thickness, this section may be verified at a great number of points in the foothill region. The andesite of the breccia eruptions is a coarse-grained rock. It is shown in the table of analyses by No. 72 Sierra Nevada, which came from the southwest base of Mt. Ingalls. No. 16 Sierra Nevada is a massive occurrence of a similar coarse andesite, but differs from No. 72 in containing hornblende to the exclusion of pyroxene.

In the area of the Downieville and Bidwell Bar atlas sheets

are numerous bodies of a dense fine-grained gray lava, which usually weathers with a slaty fracture, the apparent cleavage being often vertical. The rock is composed of plagioclase, augite, a slightly pleochroic rhombic pyroxene, and grains of magnetite. The feldspar, augite, and rhombic pyroxene are in the form of minute elongated prisms or laths, and this is true of the rock at widely separated localities, and the laths of all are nearly of the same size. About half a gram of No. 661 powdered and treated with HCl by George Steiger yielded no gelatinous silica, but nevertheless there appears to be some glass present.

Three analyses are given in the table of this pyroxene-andesite. The analysis of No. 1829 Cascade Range collection[1] is of a specimen collected by Mr. Diller, from the west summit of Crater Peak (Lassen Peak atlas sheet); No. 209 Sierra Nevada is from the high point one and one-fourth miles north-east of Goodyear's Bar; and No. 661 is from Franklin Hill (Bid-well Bar atlas sheet). The analyses of 1829, and 209 are by Dr. Hillebrand, and the partial analysis of 661 is by Dr. Stokes. In the vicinity of Poker Flat are numerous dikes of another fine-grained andesite very similar in general appearance to the variety just described. It differs in being frequently columnar, and microscopically in containing a little hornblende and in the feld-spars being less uniform in size and shape. At one point on the summit of the ridge south of Poker Flat a dike (No. 631 S. N.) of this rock cuts the hornblende-pyroxene-andesite-breccia. Another and larger dike cuts the pre-Tertiary rocks east of Poker Flat. It crosses Canyon Creek just east of the mouth of Illinois ravine, and to the southeast of Poker Flat forms a conical butte showing columnar structure. An analysis of the latter dike is given in the table (No. 262 S. N.). This andesite is therefore later than the hornblende-pyroxene-andesite-breccia. The exact relative age of the similar fine-grained andesite (Nos. 1829, 209 and 661) is still in doubt, but it is thought to be of about the same age as the andesite (Nos. 631 and 262) just described.

The rock called quartz-andesite (No. 626 S. N.) in the table

[1] Bull. No. 60, U. S. Geol. Survey, p. 157, No. 19.

of analyses of Tertiary rocks is not a dacite. The quartzes are much corroded and surrounded with reaction rims of pyroxene microlites. They may perhaps be regarded as inclusions. The rock has a pilotaxitic structure, and seems related to the fine-grained pyroxene-andesites. It forms a flat-topped hill on the ridge two miles northwest of Downieville.

Following the andesite eruptions we have at many points flows of basalts. Some of these, as, for example, the coarse doleritic basalts of Mt. Ingalls in Plumas county, are believed to belong to early Pleistocene time, for the eruptions seem to have occurred after the present drainage system was partly formed. However, on the north side of the mountain glacial striæ are to be seen on the lava, showing the flow to have taken place before the close of the Sierra Nevada glacial epoch. The doleritic basalt is represented in the table of analyses by Nos. 311 and 314 Plumas.

There are at many points isolated buttes and dikes of fine-grained basalts that do not resemble closely either the older basalt above described or the Pleistocene doleritic basalt. There is usually abundant olivine in these rocks, but their groundmass is much finer grained than that of the doleritic basalt. Their age is presumed to be Pleistocene. A dike of one of these rocks cuts the coarse andesite, and the underlying gravel of the point sometimes called Mt. Etna, one mile northeast of Mt. Fillmore (Downieville sheet) by the road to Johnsville, and similar dikes cut the Neocene fragmental material exposed on the southeast slope of Mt. Fillmore.

To the north of the Sierra Nevada at Cinder Cone,[1] near Lassen Peak, and about Mono Lake[2] just to the east, as well as in the Coast Range to the west near Clear Lake,[3] craters exist that retain nearly or quite their original forms. These volcanoes are without doubt of late Pleistocene age. Within the Sierra Nevada, however, if the range be limited as suggested in the beginning of

[1] Bull. No. 79, U. S. Geol. Survey, by J. S. Diller.

[2] Eighth An. Rep. Director U. S. Geol. Survey, pp. 378–389.

[3] Monograph XIII., U. S. Geol. Survey, p. 246.

this article, no eruptions are known to have occurred since early Pleistocene time.

The succession of the Tertiary volcanic rocks is then as follows:

ACID - - - - - - - -	Rhyolite — massive and fragmental.
BASIC - - - - - - - -	Older basalt — always (?) massive.
INTERMEDIATE - - - -	Hornblende-pyroxene-andesite — chiefly tuff and breccia.
INTERMEDIATE TO ACID -	Fine-grained pyroxene-andesites — massive.
BASIC - - - - - -	Doleritic basalts — massive.
BASIC - - - - - - - -	Other basalts — massive.

This succession does not accord with the law of Richthofen nor with Iddings' law, but it should be noted that the record here given is an imperfect one.

According to Dr. James Blake,[1] there is a variety of volcanic rocks in the Puebla Mountains in Northern Nevada forming successive flows, the relative age of which is very clear, as the series is finely exposed. Dr. Blake made some chemical determinations of the igneous rocks, but they do not appear to have been studied microscopically. Indeed, at that time (1873) the microscope was in little use in rock investigation. His conclusion as to the succession is that it does not accord with Richthofen's law, but the series he describes obviously needs further investigation.

Iddings' law[2] is perhaps the latest that has been formulated with great care and after a consideration of the succession in many parts of the world, with a large amount of original research based on extensive field study and collections at various volcanic centers in the West. It is as follows:

> The variation in the composition of igneous rocks, which constitute a series of eruptions at any volcanic center, is the result of the chemical differentiation of some intermediate magma. The composition of the intermediate magma may be different in different centers of eruption and in different regions, and it will be shown subsequently that the intermediate magma of any particular center may itself be the result of a differentiation of a more ancient magma or of a primary uniform magma, if such a thing can be shown to have existed.

[1] Proc. Cal. Acad. Sci., Vol. V., pp. 210–214.

[2] Bull. Phil. Soc., Washington, Vol. XII., p. 151.

Brögger in a late paper on the basic igneous rocks of Gran, in Norway, writes as follows:[1]

We have consequently in the basic rocks of Gran a remarkable example of the fact that one and the same magma *partly* without essential differentiation has been pressed up to a higher level, and there has crystallized out as large boss-masses (in the form of olivine-gabbro-diabase), *partly* has been differentiated at a deeper-seated level into a basic magma (which by its outburst has formed sheets and dikes with porphyritic structure, camptonites), and into a more acid residuary magma (which in the final eruptions has given rise to sheets and dikes of bostonite). This differentiation (into camptonites and bostonites) has partly also taken place in the dike and sheet-fissures themselves *after* passing up into a higher level.

This certainly confirms Iddings' law in a remarkable degree.

The chemical analyses of the igneous rocks of the Sierra Nevada given in the two tables, pages 403 and 407, are arranged as nearly as the writer is able in their order of succession. Considering now the Sierra Nevada as a whole as a petrographic province, there are certain relations which seem to suggest that Iddings' law may be applied here.

The oldest of the pre-Tertiary rocks which have a wide distribution are the augitic tuffs and breccias. These are chiefly of an intermediate character. The serpentines (originally peridotites and pyroxenites) are at a number of points clearly intrusive in, and therefore later than, these augitic tuffs. It seems to be also true that the quartz-mica-diorite (granodiorite) is later than the serpentine. This relation has already been noted[2] to the southeast of Placerville, and the quartz-mica-diorite of Indian Valley (Downieville sheet) sends out a dike-like protrusion into the serpentine where exposed in the bed rock of the Indian Hill gravel mine. In the bed of Mill Creek, one and one-half miles northeast of Big Bar Hill (Bidwell Bar atlas sheet), a dike of biotite-granite cuts the tremolite and chlorite schists which are altered forms of pyroxenites, and are in this section associated with serpentine as part of the same rock mass. About two and one-half miles south of Big Bar Hill

[1] Quart. Jour. Geol. Soc., Vol. L., p. 29.

[2] See Am. Geol., Vol. XI., p. 310.

there are streaks of serpentine, amphibolite and quartz schists forming one series which is cut off by a protrusion of the large Merrimac granite area. The succession of the most abundant of the pre-Tertiary rocks of the Sierra Nevada would then be:

INTERMEDIATE -	Augitic porphyrites and their tuffs — effusive.
BASIC - - - -	Peridotites and Pyroxenites — intrusive.
ACID - - - -	Quartz-mica-diorites — intrusive.

Brögger has introduced a term that promises to be of much use to petrographic science. He writes:[1]

> For rock-types, differentiated out of a common magma, I propose the name "complementary rocks;" camptonites and bostonites are then such complementary rocks.

The serpentine, a very basic rock, and the quartz-mica-diorite are thus perhaps later differentiations from the intermediate magma of the augitic porphyrite eruptions. It is obviously unsafe, however, to generalize on the meager data presented as to the age of all of the augitic tuffs, serpentines, and granites of the Sierra Nevada. Instead of there being one series of these pre-Tertiary rocks, it is much more probable that there are two, a Palæozoic and a Jura-Trias series, and it is far from improbable that the succession is more complicated than represented here.

Later than the quartz-mica-diorite and serpentine are the aplite dikes or veins and the late hornblende-porphyrite dikes, and these may possibly be "complementary rocks" also. Both are nearly of an age, but they are not found together, so far as the writer has observed. The dikes of hornblendic rock are abundant in the Spanish Peak and the Merrimac (Bidwell Bar sheet) and the West Point (Jackson sheet) granitic areas; and the aplite dikes are common in most of the granitic areas, but as before stated are not associated with the hornblendic dikes.

H. W. TURNER.

[1] Quart. Jour. Geol. Soc., Vol. L., 1894, p. 31.

THE STRATIGRAPHY OF THE CALIFORNIA COAST RANGES.

CONTENTS.

INTRODUCTION.

In a recent publication the writer presented a résumé of the present state of knowledge of the geology of the California Coast Ranges.[1] It is intended to devote the present article partly to a more detailed statement of views expressed in that paper on the relation of the Miocene, Upper and Lower Cretaceous to each other, which could not be fully discussed for lack of space, and partly to the presentation of additional evidence in support of the writer's published views concerning the existence of a pre-Cretaceous (pre-Knoxville) series of rocks in the Coast Ranges. Most of the observations on which the opinions presented are based were made during the summers of 1891–2–3. Valuable additions were made the past fall, when in company with Mr. F. M. Anderson, a student in Stanford University, a three weeks' trip was made through the Santa Lucia Mountains in Monterey and San Luis Obispo counties.

[1] Bull. Geol. Soc. Am., Vol. VI., 71–102.

CRYSTALLINE BASEMENT COMPLEX.

Considerable areas of granite, crystalline schists, and limestone appear at many points in the Coast Ranges between Point Reyes and Ventura county. No information has yet been gained of the age of any portion of this basement complex, beyond the fact that it underlies unconformably the most ancient uncrystalline rocks which are probably not older than the Jurassic. It would appear that the granite cannot be correlated with that which was irrupted at the close of the Jurassic in the Sierra region. It seems highly probable, from our present knowledge, that a long period of erosion, during which these crystalline rocks were much more prominently exposed than at present, ensued between the upheaval and metamorphism of the schists and limestones, and the deposition of the lowest uncrystalline strata.

GOLDEN GATE SERIES.

Definition.—Between the lowest recognized Cretaceous and the basement complex is a series of rocks separated from both by nonconformities, and everywhere characterized by rather peculiar lithologic features. For this collection of strata, consisting chiefly of jasper, sandstone, shale, and slate, typically developed about the entrance to San Francisco Bay, the designation Golden Gate series is proposed. According to our present knowledge these rocks form a conformable series of strata with a remarkable similarity of character through their whole extent. The scanty fauna thus far known indicates that it does not embrace a great range of geological time, although its thickness is very considerable. The series has been recognized by the writer from central Santa Barbara county northwestward through the Coast Ranges to the Klamath Mountains. On the western slope of these mountains it has been traced to the Oregon line, and it undoubtedly extends farther. Until recently the series has been considered, by all geologists who have published results of work in the Coast Ranges, not older than the Knoxville, of which it has often been thought to be a metamorphosed portion. In 1892 the writer first advanced the view that these rocks were

not a portion of the Knoxville,[1] but that they underlaid it unconformably. Since then in other publications[2] additional evidences have been given of the geological independence of this series, of its distinct lithological character, and of its extent in the Coast Ranges. To the writer the evidences supporting this view seem to be conclusive. Nevertheless, the old view that these rocks constituted a metamorphosed portion of the Knoxville has been accepted so long, and has become so current in geological literature, that the new one has been looked upon with more or less doubt. The writer ventures to assert, however, that if the geology of the Coast Ranges had never been touched until today, the confounding of the Knoxville with the older series beneath never would have occurred. In the light of these conditions it has seemed best to continue to put on record all observations which would aid in bringing out a full recognition of the important fact that there is an uncrystalline series of rocks in the Coast Ranges beneath the Knoxville. The importance of the correct classification will be understood when it is stated that the strata included in the Golden Gate series extend for a distance of 500 miles through California, and for an unknown distance in Oregon. The recent field work in Monterey and San Luis Obispo counties has been so fruitful in positive results that the existence of a pre-Knoxville series of uncrystalline strata must be considered proved.

Lithologic character.—One of the distinct features of this series of rocks is its peculiar and comparatively uniform lithologic character. In general it is so different from that of any of the younger formations that it can be used as a criterion of distinction by one familiar with the general character of the formations in the Coast Ranges. This becomes of the greatest value when there is taken into consideration the scarcity of fossils and the rare occurrence of distinct contacts. The jasper has until recently been considered a metamorphic rock. In a paper read before the Geological Society last August, the view was advanced

[1] American Geologist, Vol. IX., 153–166.

[2] American Geologist, Vol. XI., 69–84. Bull. Geol. Soc. Am., Vol. VI., 71–102.

by the writer that the jasper is not metamorphic, but that it is formed to a considerable extent of the remains of siliceous organisms of the radiolarian type. This opinion was based on the study of a number of thin sections of the rock from widely separated portions of the Coast Ranges. F. Leslie Ransome has recently announced the discovery of the first radiolarian remains found in a state sufficiently well preserved for description. Many specimens of jasper were collected on the recent trip through Monterey and San Louis Obispo counties, and nearly all showed the radiolaria visible to the unaided eye. The best were obtained from a large outcrop of greenish white jasper on the Eagle Ranch, six miles northwest of Santa Margarita. A microscopic study shows that portions of this rock are made up almost wholly of radiolaria which are in a better state of preservation than any previously found, fifteen or more specific forms being made out. The jasper beds vary from a few feet to more than a hundred feet in thickness, and exhibit more or less distinctly a banded structure. The bands are often contorted so as to present a beautiful wavy appearance. The accompanying illustration is from a photograph of a magnificent outcrop on the coast of Monterey near the mouth of the Sur River. It illustrates both the banding and the wavy structure. Comparatively uniform conditions must have existed over the whole of the area covered by the Golden Gate series, where the rocks were being deposited, for the jasper beds are found almost everywhere that the rocks of this series are exposed. Similar conditions did not obtain during the Cretaceous, for jasper is not known in any beds of that age on the Pacific coast. The series of beds of which the jasper forms such a striking feature undoubtedly possess a great thickness, but they have not yet been studied sufficiently in regions where the greatest development occurs to admit of any definite statement of their thickness. It is not probable that the jasper is confined to one horizon in the series, and the strata have been so sharply folded, shattered, and crushed together by orographic movements, as well as by the intrusion of numerous eruptives, that its study is accompanied by uncommon difficulties. Sandstone

FIG. I. Banded Jasper of the Golden Gate series, coast of Monterey county, California, near the mouth of the Sur River.

forms the larger part of the series wherever the writer has investigated it. The sandstone strata are often thick-bedded, which fact, taken together with the distortion undergone makes it very difficult to determine the bedding in small outcrops. Shale or slate occurs in subordinate amount, as thin layers between the sandstone strata, or more rarely in thick beds as in some portions of the Santa Lucia Mountains and the northern Coast Ranges.

Stratigraphic position.—The Golden Gate series as previously defined underlies unconformably the lowest known Cretaceous and rests on the crystalline basement rocks. It seems, for reasons to be mentioned, that no great lapse of time, geologically speaking, separated the deposition of the beds belonging to this series from the lowest Knoxville beds, but on the contrary the time interval separating it from the crystalline basement is very great. At numerous points along the coast of Monterey county this Golden Gate series rests on the granite and crystalline schists. For a distance of three or four miles in the vicinity of Slate's Springs it terminates below with a conglomerate which, on Hot Spring Creek, is 1000 feet thick.

The question of the relation between the Golden Gate series and the Knoxville is the all-important one. As far south as the fortieth parallel Mr. Diller has proved the existence of a series older than the Knoxville and separated from it by a nonconformity. Four miles east of Lower Lake the writer has observed an undoubted nonconformity between the *Aucella*-bearing shales and the older series. About Clear Lake the Chico rests unconformably on upturned masses of sandstone, jasper, and slate. In the Cañon of Capel Creek, Napa county, there are good evidences of a nonconformity between the Knoxville and an older series. In the Coast Range south of San Francisco the writer has observed the Chico at many points resting unconformably on a series of rocks lithologically very similar to that underlying the Knoxville farther north. The recent trip through the Santa Lucia Range resulted in the discovery of several distinct contacts between the *Aucella*-bearing Knoxville shales and an under-

lying series of jasper and sandstone. The most northerly known occurrence of the Knoxville beds in the Santa Lucia Range is on Pine Mountain opposite the town of San Simeon. The Knoxville beds here outcrop on the very summit of the range, being partly capped by liparite. They have an exposure of at least two miles from northwest to southeast and a width of a mile. The lower slopes of the mountain surrounding the beds consist of jasper, sandstone and dark, fine-grained eruptives. A section exposed along the grade of an old road crossing the mountain makes it very evident that the Knoxville overlies these rocks unconformably, but no good contacts were found there owing to the enormous amount of débris. On the southern slope the Knoxville beds are well exposed, dipping northerly at a gentle angle. To the east they are replaced by a ridge formed of hard sandstone and jasper, and in a little gulch eroded between these two formations, their relation to each other is distinctly shown. At one point the bottom and east side of the gulch consists of gray sandstone with thin, irregular layers of shale having a vertical dip and a north and south strike. On the west side the Knoxville shales, *Aucella*-bearing a few hundred feet above, appear in contact with the sandstone, dipping west at an angle of 40°. A short distance further up the gulch the Knoxville shales extend up to and overlie the gray sandstone with as marked a discordance in dip as that first noted. Less than one hundred feet away green jasper is interstratified with the sandstone.

Another area of the Knoxville beds occurs in the same range, north of the town of San Luis Obispo. The beds form much of the mountainous area extending from the railroad tunnel northwest for about fifteen miles. On the southwest these beds rest against a great serpentine ridge which forms one of the crests of the range. On the northeast they are underlaid by the sandstone and jasper of the Golden Gate series. At many points about the heads of Toro and Morro Creeks the Knoxville appears to have no great thickness, for it flanks the little hills and ridges of the Golden Gate series which project through it in the most

irregular manner. Numerous points were found where the contact was obscured by only a few feet of débris. The *Aucella* appeared widely distributed in the shales and sandstone, but its stratigraphic position could not be determined because of the complexity of the structure. On the summit of the range between Morro Creek and the Arroyo Atascadero a narrow arm of the Knoxville shales and sandstone is folded in vertically between ridges of the older series. The contact is plainly shown in the bed of a dry arroyo. Specimens of *Aucella* were obtained from a coarse sandstone blending into a conglomerate at a point which was apparently the lowest portion of the beds.

The Golden Gate series projects through the Knoxville in many places near the Eagle Ranch House. The former consists of jasper, sandstone and shale with large bodies of greenish, fine-grained eruptives. Absolute contacts showing an unconformable superposition of the Knoxville are rare because of the amount of soil everywhere present. More than a score of instances were noted where the contact between the two formations was hidden by only a slight amount of soil so that a few hours' work with a shovel would uncover it. The contacts already found, however, showing an unconformity, taken together with those where it is probable though not distinctly shown, and which would be accepted without hesitation by one thoroughly familiar with the two formations, establish on stratigraphic grounds the existence of an uncrystalline series below the Knoxville.

Faunal relations.—Fossil remains characteristic of a definite horizon have not yet been found in the Golden Gate series. This is a most remarkable fact when there is taken into consideration its extent, and the amount of study which has been given to it. The first fossil found in rocks which the writer would refer to this series is the *Inoceramus elliotti*, Gabb, from Alcatraz Island, obtained by Whitney. This was considered at the time as positive proof of the Cretaceous age of the San Francisco sandstone. In the summer of 1892 the writer obtained several poorly preserved specimens of *Inoceramus* from a bed of black

slate at Slate's Springs on the coast of Monterey county. This locality was revisited the past fall in company with Mr. Anderson, and a collection made embracing five species of lamellibranchs and a number of plants. The former though somewhat crushed were well enough preserved for generic determination. Unfortunately they proved to be very puzzling and threw but little light on the question at issue. They were submitted to Mr. T. W. Stanton for determination and the following description is given by him: "The collection includes a large species of *Inoceramus*, a large *Homomya* (?), *Macrodon*, *Leda* and *Rhynchonella*, none of which can now be referred to described species. The *Inoceramus* seems to me the most important form in determining the age, as it is confined to the Mesozoic, and a species of this size and type is probably not older than the Jurassic and might be Cretaceous. *Inoceramus quatsinoensis*, Whiteaves, from the *Aucella*-bearing Cretaceous beds of Vancouver is a similar species. Taking this in connection with the statements of yourself and Mr. Anderson concerning the field and stratigraphic relations of the beds, the most reasonable inference would seem to be Jurassic. The other fossils apparently do not conflict with this reference."

In the absence of confirmatory evidence the *Inoceramus* from Alcatraz Island cannot be accepted as proof of the Cretaceous age of the strata there, and it is very probable that the horizon represented is the same or nearly the same as that of the Slate's Springs beds.

The recent discovery of radiolaria in the jasper of the Golden Gate series not only adds greatly to the interest of these rocks but also may aid in the solution of the age problem. Those found by Mr. Ransome and Professor Lawson, and submitted to Mr. Hinde for examination, are, according to his description, forms similar to those occurring in the jasper of the Upper Jurassic and Lower Cretaceous of Europe. A part of the European beds containing the radiolaria are believed to belong to the upper Jurassic, while opinion is divided as to the exact horizon of the others. The specimens obtained by the writer

from the Eagle Ranch resemble those from Angel Island, but the number of species is greater and the state of preservation better in many cases. In Vol. XXXI. of the Palæontographica Rüst gives a plate on which are figured a group of radiolaria from the red jasper of west Switzerland which belongs to the upper division of the Jurassic. A comparison of the figures on this plate with those in a slide from the Eagle Ranch shows a remarkable similarity of the forms. At least five forms in the slide are closely allied to those on the plate.

It will be seen that as far as faunal evidence is concerned the question cannot yet be considered as satisfactorily settled. This much can be said, however, that the fossil remains found on the one hand in the jasper in different portions of the series, and in the slates near its base on the coast of Monterey, indicate with a strong degree of probability that the series as a whole is not older than the Jurassic and may belong to its upper division. Some of the forms, especially that of the *Inoceramus*, are very closely allied to known Cretaceous species, so that if palæontology alone had to be relied upon the question is at present a puzzling one. When, however, in addition to the faunal evidence, there is taken into account the fact of the unconformable position of the series beneath the Knoxville, the writer believes that its horizon can be stated with a considerable degree of certainty as Upper Jurassic. It may be best to add here that the application of the term Jurassic to this series is based on the fact that the Knoxville is at present considered by palæontologists as belonging to the Lowest Cretaceous. The writer does not wish to be understood as contending in this or in other articles previously published for a Jurassic series *per se*, but for the recognition of the existence of an uncrystalline series underlying the base of the Knoxville.

Stratigraphic position of the beds at Slate's Springs.—Lithologically the strata are entirely different from any portion of the known Cretaceous on the Pacific coast. They are considerably metamorphosed and in places extremely distorted and broken. They stand nearly vertical and consist of alternating layers of

sandstone and slate. They are followed downward by a thick conglomerate, while other layers of similar conglomerate are exposed in the edge of the ocean. The whole series has an exposed thickness of 1500 feet from the base to the ocean cliffs, and extends an unknown distance beneath the sea. The slates and sandstones form a narrow belt, at times almost cut out by bodies of eruptive origin, for a number of miles down the coast. They gradually widen out to form the great area of pre-Knoxville rocks of the Santa Lucia Mountains in southern Monterey and northern San Luis Obispo counties. Four miles south of Slate's Springs and north of Big Cañon bodies of jasperoid rocks are associated with the sandstone. On the ridge south of Big Cañon are a number of outcrops of red jasper. At the mouth of Mill Creek is another body of jasper. Near the mouth of Vicente Creek slates outcrop along the cliffs facing the ocean, bearing the closest resemblance to those at Slate's Springs. A short distance south of Vicente Creek there are large outcrops of a banded red jasper. The Slate's Springs beds thus appear to be both stratigraphically and lithologically continuous with the Golden Gate series which on Pine Mountain underlies the Knoxville beds unconformably. Mr. Anderson, who has given considerable study to the Cretaceous of Oregon and northern California, agrees entirely with the writer with regard to the strongly marked lithological contrast between the strata at Slate's Springs and the Cretaceous, and their resemblance to portions of the Auriferous Slate series.

THE TIME INTERVAL BETWEEN THE KNOXVILLE AND THE GOLDEN GATE SERIES.

The great deformation exhibited by the Golden Gate series, its much higher degree of solidification and partial metamorphism, the numerous included bodies of eruptives formed prior to the deposition of the Knoxville, and the marked nonconformity between it and the Knoxville, all point to a time interval of considerable extent, during which there were violent disturbances terminating in its elevation and erosion. This interval may

represent a portion of the uppermost Jurassic or possibly the very base of the Cretaceous. Dr. White has represented graphically the position of the different divisions of the California Cretaceous in his Correlation papers. According to this the extreme basal portion of the Cretaceous is absent. The more recent work of Messrs. Diller and Stanton, which has been carried out with the greatest care, places the Knoxville at the base of the Cretaceous. This places the Golden Gate series in the Jurassic, and probably at a horizon which corresponds very closely with that represented by the Mariposa beds. Although the fauna at present known from the Golden Gate series is indeterminate in its time relations, as far as the Jurassic or Cretaceous is concerned, the pronounced nonconformity between it and the Knoxville must be taken into account. The interval necessary for the deformation, metamorphism and erosion of the lower series must have been considerable, and is to be correlated with that found by Mr. Diller to exist between the Upper Jurassic beds of northern and central California, and the Shasta-Chico series of the Sacramento Valley. The increasing mass of evidence is in favor of the views of Mr. Diller concerning the synchronism of the great revolution in the Sierras and the Klamath Mountains, which he holds took place near the termination of the Jurassic. Accepting this as true, as the writer has stated in former publications, a demonstration of the extension of this nonconformity southward also proves that the underlying rocks are at least as old as the Jurassic.

THE NONCONFORMITY BETWEEN THE CHICO AND KNOXVILLE IN THE SOUTHERN COAST RANGES.

In several papers the writer has expressed the opinion that there is evidence at many points in the Coast Ranges of the existence of a nonconformity between the Chico and Knoxville beds. This nonconformity is supposed to be due in part to a post-Knoxville elevation when numerous bodies of peridotitic eruptives were formed. As far as is known the Horsetown beds are absent from the Coast Ranges south of San Francisco. Until recently the Upper and Lower Cretaceous had not been

found together in that portion of the state, and their relation to each other was more or less a matter of inference. The contact which has just been found is on the Eagle Ranch in the Santa Lucia Range. The central portion of the range is there formed of Knoxville shales and sandstone carrying *Aucella*, the total width exposed being about three miles. The Knoxville is bordered on the west by a great dike of serpentine, while on the east a nearly hidden axis belonging to the Golden Gate series projects through it in numerous places. The Knoxville presents a very much disturbed condition, partly due to the dikes of serpentine. The Chico, consisting almost wholly of heavy-bedded sandstone, rises on the eastern slope, overlapping the Knoxville shales and capping portions of the first line of hills. It has not undergone the same amount of disturbance as the Knoxville and is nowhere folded in with it, appearing rather as a thin capping on an irregularly eroded surface. Fossils were sought for a long time in the sandstone without any result. Finally a number of poorly preserved specimens were obtained from the summit of a hill about one mile south of the Ranch House. The following is the list: *Baculites chicoensis*, Trask. *Trigonia evansana* (?), Meek. *Pectunculus veatchi*, Gabb, *Cucullaea sp.*, *Pentacrinus sp.* In a small ravine near the spot where the fossils were obtained there is a contact between the sandstone and the dark shales. This ravine extends up the west side of the hill making a slight depression nearly to its summit. The northern portion of the hill is capped with a thin layer of the Chico sandstone, dipping south at an angle of 30°. The sandstone extends to the bed of the ravine and is there exposed resting on the shales. The latter are well shown, not only underneath the sandstone but also on the slope of the hill south into which the dip of the sandstones would carry them. The sandstone has a very regular bedding while the shale underneath is so broken that the stratification is not distinctly visible. The spot was examined particularly with reference to the possibility of the phenomena being due to faulting, but no evidence of it could be discovered. Fossils were not found in the Knox-

ville near the sandstone, but at the base of the hill one-half mile distant, in strata which could be traced by continuous outcrop to the contact. On the north fork of the Atascadero, three miles northwest of this locality, is an *Aucella*-bearing stratum folded in between the older rocks. About 500 feet north of the vertical Knoxville shales is a hill capped with a body of Chico sandstone with only slightly inclined bedding planes. This hill lies directly in the strike of the shales, and although no contact is visible there can be no doubt of an unconformity.

THE RELATION OF THE SERPENTINE TO THE CHICO-KNOXVILLE UNCONFORMITY.

The absence of the Horsetown beds and the presence of numerous large bodies of serpentine favor the supposition of a break between the upper and lower divisions of the Cretaceous. Serpentine occurs intruding the Knoxville and older rocks at many points along the Santa Lucia Range. It seemed probable that such was the case on Pine Mountain although no good exposures were found. Near the Old Padre mine, west of Santa Margarita, the Knoxville shales in contact with the serpentine are considerably metamorphosed. On the Eagle Ranch a dike of serpentine has been cut on one of the grades, showing its intrusion in the Knoxville shales. The writer has never seen serpentine intruded in the Chico in any portion of the Coast Ranges, and all indications point to its formation during the interval between the deposition of the Knoxville beds and the Chico. In the southern Coast Ranges at least, the disturbance must have caused an elevation of the Knoxville, so that during the period represented by the deposition of the Horsetown beds in northern California, the former must have been above water and undergoing erosion.

THE NON-CONFORMITY BETWEEN THE MIOCENE AND THE CHICO-TEJON SERIES.

An examination of geological literature relating to the Coast Ranges shows that the Miocene has generally been held to have been deposited conformably on the Chico-Tejon series. This

question had not been studied in the southern Coast Ranges prior to the work done there by the writer. In that field numerous occurrences were noted where the Miocene unconformable overlaid the Chico, or Tejon, as the case might be. The non conformity was pronounced wherever contacts could be found, for a distance of 200 miles, through the counties of Ventura, Santa Barbara, San Luis Obispo, and Monterey. Topographically the southern portion of this region is very rugged and difficult of exploration. The deep cañons and brushy mountains rising 5000–7000 feet make access to it almost impossible except along the scattered trails. Geologically portions are quite complex but there are large areas where the Cretaceous, Lower and Middle Tertiary are the only horizons represented. The assemblage of strata belonging to the Upper Cretaceous and the Lower Tertiary, known in geological literature as the Chico-Tejon series, is particularly prominent in northern Ventura and southern Santa Barbara counties. The Miocene not only forms complete mountain ranges, as for example, the Santa Ynez, but also appears as fringes along the Chico-Tejon elevations and in detached areas almost on their very summits. Beginning in northern Ventura county the various localities will be described where the relation of the Miocene to the Chico and Tejon was observed. Pine Mountain in northern Ventura county extends in an east and west direction between Cuyamas River on the north and the Sespe on the south. It forms the northern portion of a great thickness of dark shales and sandstones which have a width, north and south across their line of strike, of nearly twelve miles. Fossils were collected from two localities on this section, but so complex is the structure that the exact position in the series was not determined, although it seems that they are from the upper portion. On the northern slope of Pine Mountain the following fossils were collected: *Meretrix horni*, Gabb; *Fusus remondi*, Gabb; *Neverita globosa*, Gabb; *Dentalium pusillum*, Gabb; *Turris varicostata* (?), Gabb; *Actæonella oviformis* (?), Gabb; *Turritella sp.* The horizon indicated is the Tejon. Near the head of the Matilija Cañon, about eight miles southward, there was collected the

following Tejon forms : *Crassatella grandis*, Gabb ; *Meretrix horni*, Gabb ; *Cardium sp.; Fusus martinez*, Gabb ; *Dentalium cooperi*. The Sespe in its upper course has eroded a broad longitudinal valley in the center of this formation. North of the stream on the southern slope of Pine Mountain is a body of heavy-bedded light yellow sandstone, dipping north generally at a small angle. Where the Matillija trail crosses it there were found numerous specimens of *Astrodapsis whitneyi*, Remond ; fragments of *Ostrea titan*, Con., and *Pecten discus*, Con. Four miles down the cañon Dr. Bowers[1] has collected twenty-five Miocene species from the same sandstone. Although the actual contact was not observed, there can be no doubt as to the unconformity. The Tejon and possibly Chico strata below being steeply inclined and much broken, especially south of the Sespe, while the Miocene sandstone dips very regularly to the north into the Tejon, forming the summit and north slope of Pine Mountain. Near the mouth of Santa Barbara cañon there is a series of sandstones, gypsum-bearing clays, and limestones resting unconformably against dark thin-bedded sandstones and shales of undoubted Cretaceous age, although no fossils were found at this point. South of the Perkin's Ranch on the slopes of the Cuyamas Range are numerous areas of light yellow heavy-bedded sandstones resting on or against dark sandstones and shales. Specimens of a Miocene *Pecten* and *Ostrea* occur in the upper beds at different points. The following Chico fossils were found in the deep cañon of the Sisquoc, between the Cuyamas Range and the San Rafael Mountains : *Inoceramus, sp.; Meekia sella*, Gabb ; *Pectunculus veatchi*, Gabb ; *Cinulia obliqua*, Gabb ; *Baculites chicoensis*, Trask ; *Cylichna costata*, Gabb ; *Tellina ashburneri*, Gabb ; *Dentalium stramineum*, Gabb, and an unknown crustacean. The strata consisting of dark shales and thin-bedded sandstones are steeply tilted and much broken. Stratigraphically they seem to belong with the lowest beds in Santa Barbara Cañon. The uppermost beds at the head of the latter cañon occupy the highest position in a great synclinal fold, appearing to be a continuation of the Tejon on Pine Mountain. South of the Sisquoc,

[1] Report Cal. State Mining Bureau, p. 763.

capping the high mountains between it and the Manzana River, is a large area of light yellow sandstone, apparently not greatly disturbed. Continuing up the Sisquoc these sandstones were finally observed outcropping on the bank in direct contact with the Cretaceous. The discordance in dip of the two formations is about 15°. There does not seem to be any doubt about the reference of the sandstones to the Miocene, as they correspond exactly to the known Miocene only a short distance to the north. In the lower end of the Cuyamas valley are horizontal strata of incoherent sandstones bearing *Ostrea titan* and a species of *Pecten*, while only a short distance below are steeply inclined conglomerates and sandstones referable to the Chico.

In a small tributary cañon of the Santa Ynez River, below the old Mission, is a contact between a body of dark shales, closely simulating the Knoxville, and light yellow sandstone. The sandstone rests on the shales with a discordance in dip of 20°. In the shales no fossils were found, but in the sandstone two species were obtained: *Ostrea panzana* (?) Con., and *Pecten pabloensis* (?) Con. That portion of the Santa Lucia Range lying in southern San Luis Obispo county consists largely of heavy-bedded sandstones and conglomerates, which according to our present knowledge are wholly referable to the Chico. Near the head of the Santa Margarita Valley specimens of *Trigonia evansana*, Gabb, and *Axinea veatchi*, Gabb, were obtained from the sandstone. Five miles farther north several specimens of *Venus lenticularis*, Gabb, were found in a nodular mass of limestone in the same sandstones.

An excellent section of the Bituminous Slate series (Miocene) is shown for many miles along the Arroyo Grande which has its source in the Santa Lucia Range. Near its head in the vicinity of Music are extensive beds of sandstone carrying *Ostrea titan*, Con., and *Astrodapsis whitneyi*, Remond. Fully 2000 feet below this sandstone in the same series of rocks is a considerable thicknesss of soft argillaceous sandstone containing the following Miocene species: *Pectunculus patulus*, Con., *Leda cœlata*, Hds., and *Arca microdonta*, Con. Between 200 and 300 feet below

these fossiliferous beds the Miocene terminates in a soft, white sandstone. This rock rests against nearly vertical beds of hard sandstone and shale which without much doubt are referable to the Chico, as they can be traced by continuous outcrop to localities where fossils of that age were found.

A narrow belt of Miocene shales extends diagonally across the Santa Lucia Range from a point west of Templeton to the head of Santa Rosa Creek. On the north fork of the Arroyo Atascadero this shale is filled with fish remains and the mollusk, *Pecten peckhami*, Gabb. The shales overlie rocks of the Golden Gate series and dip nearly vertically. Directly in line of their strike rises a hill of Chico sandstone, the bedding of which is nearly level. The Miocene can be traced by outcrop to within a few feet of the Chico; it was evidently deposited on the eroded surface of both the Golden Gate series and the Chico. The same white shales occur on the Eagle Ranch about three miles southeast of this point. There they dip about 30° southwestward apparently resting on the yellow Chico sandstones whose outcrop was obtained within 150 feet of the shales. The sandstone shows at many places a uniform dip of 20° to 30° to the northeast. West of the white shales is a hill of jasper partly capped by the Chico sandstone. The dip of the shales at the base of the hill is such that if extended they would pass beneath the two older formations. All the phenomena shown here point to the deposition of the Miocene on the eroded surface of the Chico.

CONCLUSION.

The correct determination of the age of the Golden Gate series is one of the most important questions in Coast Range geology. The accumulating evidences are strongly in favor of the view of its Upper Jurassic age. There can no longer be any doubt as to the unconformable position of the series beneath the Knoxville, and the fauna indicates that it is not older than the Jurassic.

If future detailed examinations should prove that the Horsetown beds are absent from the southern Coast Ranges, there

must be postulated a considerable period during the middle of the Cretaceous in which that region was elevated and undergoing erosion.

The Chico-Tejon has a thickness of at least 20,000 feet in several places. We have no knowledge at present of a stratigraphic break in the series, but the direct superposition of the Miocene on the Chico in many localities lends some degree of probability to the view that a break exists.

The Miocene exposed on the Arroyo Grande has a thickness of from 5000 to 8000 feet. The succession of strata from the top downward is as follows: (1) Bituminous slate, (2) Sandstone carrying *Ostrea titan*, (3) Bituminous slate and argillaceous sandstone.

In the vicinity of the Eagle Ranch there is one of the most interesting associations of strata of different age to be found in the Coast Ranges. Four formations are present from all of which fossils were obtained: The Miocene, Chico, Knoxville and Golden Gate series, each being separated from the others by a nonconformity.

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BERKELEY, California.

STUDIES IN THE NEOCENE OF CALIFORNIA.[1]

CONTENTS.

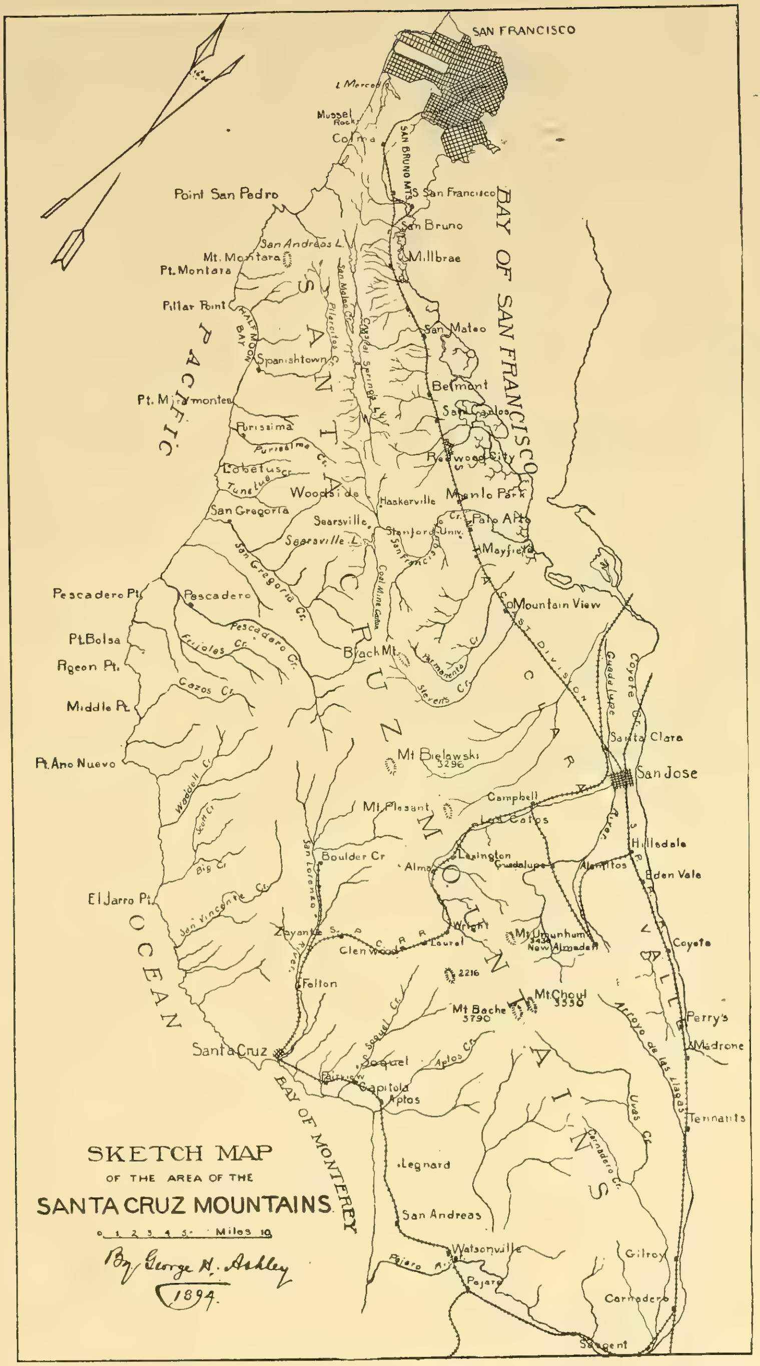
INTRODUCTION.

THE Santa Cruz Mountains, one of the Coast Ranges, lie just south of the city of San Francisco, and occupy a region about sixty-five miles long by twenty-five wide as a maximum. The whole region is an intricate series of ridges and narrow, deep valleys. The highest points rise nearly 4000 feet. The main axis has a northwest and southeast trend, and as the coast here lies nearly north and south, the ocean has cut a diagonal cross-section of its northern end, giving an excellent opportunity for the study of its history.

GENERAL GEOLOGY.

All around the edge of the mountains are nearly level plains formed partly by erosion, partly by the deposition of horizontal, unconsolidated Quaternary deposits.

[1] Abstract of a paper presented at Leland Stanford Junior University for the degree of Doctor of Philosophy.


SAN FRANCISCO
Mussel Rock
Colma
SAN BRUNO MTS.
S. San Francisco
San Bruno
Millbrae
BAY OF SAN FRANCISCO
Point San Pedro
San Andreas L.
Mt. Montara
Pt. Montara
Pillar Point
HALF MOON BAY
Spanishtown
PACIFIC
Pt. Miramontes
Purissima
Lobetus Cr.
Tunitus
San Gregoria
Woodside
Haskerville
Searsville
Searsville L.
San Mateo
Belmont
San Carlos
Redwood City
Menlo Park
Palo Alto
Stanford Univ.
Mayfield
Mountain View
Pescadero Pt.
Pescadero
San Gregoria Cr.
Pescadero Cr.
Pt. Bolsa
Pigeon Pt.
Middle Pt.
Pt. Ano Nuevo
Butano Cr.
Cazos Cr.
Black Mt.
Stevens Cr.
Coal Mine Cañon
SANTA CRUZ MOUNTAINS
Mt Bielawski
3296
Santa Clara
San Jose
Guadalupe
Coyote Cr.
Campbell
Los Gatos
Mt. Plesant
Boulder Cr
Alma
Lexington
Guadalupe
Almaden
Hillsdale
Eden Vale
Waddell Cr.
Big Cr.
El Jarro Pt.
San Vincente Cr.
OCEAN
San Lorenzo River
Zayante
S. P. C. R. R.
Glenwood
Laurel
Wright
Mt Umunhum
New Almaden
2216
Felton
Mt Choul
3530
Mt Bache
3790
Coyote
SANTA CLARA VALLEY
Perry's
Madrone
Santa Cruz
Soquel Cr.
Soquel
Aptos Cr.
Capitola
Aptos
BAY OF MONTEREY
Arroyo de las Llagas
Uvas Cr.
Tennants
Legnard
San Andreas
Watsonville
Pajaro R.
Pajaro
Gilroy
Carnadero
Sargent
SKETCH MAP
OF THE AREA OF THE
SANTA CRUZ MOUNTAINS.
0 1 2 3 4 5 Miles 10
By George H. Ashley
1894.

Unconformably below these deposits lies a series of sandy and clayey strata, partly consolidated, having locally a thickness of nearly a mile. This series, called recently by Professor Lawson[1] the Merced series, has been gently folded and has now been largely removed from the higher parts of the range. It is quite fossiliferous, and exhibits an interesting life history. In age it is mainly Pliocene, but appears to run into the Pleistocene above, and into the Miocene below.

Conformably below the Merced series is the Monterey series, one of the earliest of California formations to be studied and described. It is a great thickness of light-colored, bituminous shale, containing few fossils, and similar in structure to the Merced series. It is of Miocene age.

Unconformably below the preceding series, and having considerable prominence in the Santa Cruz Mountains, is a great series of sandstones, shales, and conglomerates, which we propose to call the Pescadero series. They consist in part of the San Francisco sandstone of previous writers. The section near Pescadero gives a questionable thickness of over 10,000 feet. They have been greatly disturbed and faulted. Their age has been shown to be in part Miocene, and is thought to extend down through the Eocene and possibly into the Cretaceous.

Still more prominent about San Francisco and through the Santa Cruz Mountains is a group of metamorphic and igneous rocks. They are cherts, sandstones, limestone, granite, serpentine, etc. They might be grouped together as the pre-Tertiary rocks of the Coast Ranges.

A small amount of Tertiary igneous rock occurs in the Santa Cruz Range.

STRATIGRAPHY.

Below is given a columnar section of the Santa Cruz Mountains. The formations there given will be briefly described, beginning with the oldest.

The metamorphics.—Under the term metamorphics may be included the beds of limestone occurring through the mountains,

[1] Univ. of Cal., Bull. Dept. of Geol., I., 143.

the granite forming the core of the range, the metamorphic sandstone, the thin-bedded chert, and the serpentine.

The limestone, whose age is unknown, occurs in two beds, extending southward from near Point San Pedro.

COLUMNAR SECTION OF THE SANTA CRUZ MOUNTAINS.

Pleistocene		Subaërial deposits. Marine deposits. Subaërial deposits.	*Elephas*, conifers.	Thickness 2000 + ft.
Pliocene	Merced Ser.	Fossiliferous beds of sandstone, shale, and conglomerate. Transitional from the Miocene to the Pleistocene.	Living shells *Mactra* (not *Venus*) *pajaroensis.* Large *Pectens*, *Arcas*, etc. Cetacean bones.	Thickness 4700 + ft.
Miocene	Monterey Ser.	Bituminous or White Miocene shale; with some sandstone.	Infusoria. *Pecten peckhami*, *Tellina congesta.*	Thickness 1000 ft.
Eocene?	Pescadero Ser.	Sandstones and conglomerates; Carmelo series (?) Pescadero sandstones and shales.	*Turritella hoffmanni.* *Ostrea titan.* *Liropecten estrellanus.* *Dosinia*, etc.	Thickness 2000 to 10,000 ft.?
Cretaceous?		The "San Francisco sandstone" (in part). Aucella beds.	Plant remains. *Inoceramus.* *Aucella.*	Thickness ?
Pre-Cretaceous		Radiolarian chert or phthanite. Metamorphic sandstone. Gavilan limestone.	Radiolaria. Foraminifera.	Thickness ?

It is usually highly crystalline, and, though of great thickness, is not prominent in the mountains.

The granite appears prominently in only two ridges; from Point San Pedro southward a few miles, and from Santa Cruz to Pescadero Creek. Occasional outcrops, however, show that it has considerable body under the main ridge. It is thought to be

younger than the limestone and the other metamorphics. The cherts have been described by Mr. Becker under the name of phthanites,[1] and more recently by Mr. F. Leslie Ransome as radiolarian cherts.[2] They are usually dark brown, thin bedded, much contorted siliceous rocks, very characteristic wherever found in the Coast Ranges. The only fossils thus far found in them are *Radiolaria*, and these have led to the belief that the rocks are of Jurassic or Cretaceous age. In connection with the radiolarian chert there frequently occurs a metamorphic sandstone, ranging in color from light yellow to dark brown. It usually shows evidence of having been subjected to agencies which have obliterated nearly all bedding planes, produced secondary silicification, and frequently reduced the whole to a structureless mass.

In various parts of the range are considerable areas of serpentine and kindred rocks. The origin of this serpentine has been the subject of much discussion. There can now be no doubt but that it is a decomposition product of peridotes and other igneous rocks with which it is associated.

The relation of the metamorphic rocks to each other and to the younger rocks is very obscure, and the subject will not be taken up here.

THE PESCADERO SERIES.

The San Francisco sandstone was one of the earliest formations recognized and described in California. By Professor Blake it was assigned to the Tertiary.[3] It was later found that the fossils upon which his conclusions were principally based came from the Pliocene of the Merced series. Professor Whitney called the formation Cretaceous, classing the metamorphic rocks with it.[4] Recent writers have thought the metamorphics and San Francisco sandstone pre-Cretaceous.[5] The writer has been able to verify Professor Blake's first conclusion. The sandstone

[1] Monograph XIII., U. S. Geol. Sur., 1888.

[2] Univ. of Cal., Bull. Dept. Geol., I., 199–200.

[3] Rep. Geol. Recon. of Cal., 1858, p. 153.

[4] Geol. Surv. of Cal., Geology, I., 77, 24, etc.

[5] American Geologist, IV., March, 1892, 133.

has been traced from outcrop to outcrop from San Francisco, through the San Bruno Mountains to Point San Pedro, and down to Pescadero where there is for about four miles a continuous exposure of the series with a perpendicular dip. At one end of this series were found characteristic Miocene fossils, such as *Turritella hoffmanni.* This clue was then followed back into the mountains to other localities yielding a more abundant fauna from which may be mentioned *Ostrea titan* and *Liropecten estrellanus.*

Having thus shown that a part at least of what has been known as the San Francisco sandstone is of Miocene age, it is believed that most, if not all, of those localities from which *Ostrea titan* and the associated fauna have been reported will be found to show the presence of the Pescadero series.

In Bear Creek Valley near Haakerville fucoids occur in a light-colored sandstone. Mr. Gabb correlates these rocks with what has since been shown to be Tejon (Eocene) in the Monte Diablo region. As the strata near Haakerville are believed to form part of the Pescadero series, some evidence is thus afforded that the Pescadero series is in part of Tejon age.

In the head waters of Stevens' Creek, and in Alum Rock Canyon in the Mount Hamilton Range near San Jose, are found the fossiliferous strata of the Pescadero series.

Lithology and stratigraphy.—The Pescadero rocks may be described under three facies, the first two of which everywhere grade into each other, the last being more distinct.

The first is typically developed at Point San Pedro. The exposure there consists of dark and black shales and shaly sandstones which, while showing finer bedding, are distinctly bedded in layers of one to three inches or more in thickness. These beds weather into soft yellow layers. This facies is well exposed in San Francisco in the deep cut on Second street. The second facies is the sandstone described by Whitney as the San Francisco sandstone; a heavy-bedded sandstone, yellow or brown where weathered, but a dark gray blue where freshly exposed. In places the beds are a foot or two in thickness, and the strati-

fication is distinct. In other places the strata are heavily bedded and frequently so intersected with joint planes that it is difficult to make out the real bedding.

These two facies were not found occupying definite horizons, but, as in the Pescadero section, grade into each other irregularly in the vertical section.

The third facies is more characteristic. It is hard, brown or dark colored conglomerate, heavy bedded, the pebbles of metamorphic rock are from one to four inches in diameter, and are sometimes distinctly faulted.

The Pescadero section gave a questionable thickness of over 10,000 feet. The exposure is cut off on the north by a nonconformity, and on the south by a fault. The conglomerates at the top or south end of the section have a thickness of 720 feet. It is thought that the Carmelo series of Professor Lawson[1] may be only a local development of the conglomeratic facies.

Occurrence.—The Pescadero series is well exposed at Benicia; in the northeastern quarter of San Francisco; in the San Bruno Mountains, and all through the Santa Cruz, Mount Hamilton and Monte Diablo Ranges. It will probably be found to be widespread throughout the Coast Ranges.

Relations.—No evidence of nonconformity between the Pescadero series and the metamorphic sandstone and phthanite was found, although one probably exists. The lowest Eocene and the uppermost Cretaceous are, as yet, unknown in California, and in the southern part of the state Chico beds lie unconformably on Knoxville, showing the absence of Horsetown strata.

THE MONTEREY-MERCED PERIOD.

The Monterey series was long ago described and assigned to the Miocene, and later investigations have not modified that decision.

The Merced series was first mentioned by Whitney, who merely speaks of the finding of Pliocene strata on Seven Mile Beach[2] by Gabb and Remond. Until recently these beds seem

[1] Univ. of Cal., Bull. Dept. Geol., Vol. I., p. 19.

[2] Geol. Surv. of Cal., Geology, I., 79.

to have commanded but little attention. They were recently described more in detail by Professor Lawson, by whom they were called the Merced series.[1] They have been called Pliocene by all who have worked on them. From Half Moon Bay southward at a number of places occur very fossiliferous beds which have often been referred to, but of which very little has been written. The fossils obtained from these beds have been referred by some to the Miocene, by others to the Pliocene. The same beds have been referred to the Pliocene where little disturbed, and to the Miocene where much disturbed.

The field-work of the writer has shown:

1. That, though minor oscillations have occurred, there was continuous sedimentation from the beginning of the Monterey period to the end of the Merced.

2. That the two series are similar in structure, that structure having been determined by the movement which took place at the end of the Merced period.

3. That the fossiliferous beds south of Half Moon Bay are conformable with the Monterey series below them and with the Merced series above them.

4. That the Monterey series is Miocene; that the Merced series on Seven Mile Beach is principally Pliocene, and that the fossiliferous beds, transitional between the two, contain a mixture of Miocene and Pliocene forms. In other words if a line were drawn between the Miocene and the Pliocene it would not come at the top of the Monterey series, as usually defined, but from one hundred to several hundred feet higher—somewhere in the fossiliferous beds.

It would be difficult, if not impossible, to draw the line between the two ages, as it would be largely governed by individual inclinations. Accordingly the writer prefers simply to call them the Transition beds of the Merced series, grouping them with the Merced series because lithologically they are similar to the predominating rocks of that series.

[1] Univ. of Cal., Bull. Dept. of Geol., I., 143.

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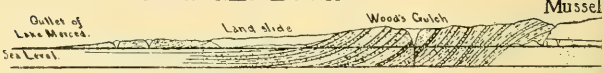


Section from San Gregorio to Pigeon Poi

Vertical scale twice the horizontal s

THE MONTEREY SERIES.

Lithology.—The rocks of the Monterey series are for the most part of a nearly white or light buff color, soft and porous, without grit, yet resisting weathering in a remarkable manner. They are usually quite thin-bedded, the bedding being very distinct. The porosity has been found in some cases to be due to the leaching-out of minute shells, probably those of foraminifera. Usually bituminous, they are locally like a coarse-grained sandstone in which the matrix is bitumen. In places they are silicified into chert. At Monterey and other places they are rich in infusorial forms, diatoms, sponges, etc., so that the beds have been considered a vast deposit of such forms. Recently Professor Lawson has advanced the idea that the White shale is of volcanic origin.[1] It is difficult on that theory to account for its occasional presence in the Merced series. The series has a thickness of about 1000 feet.

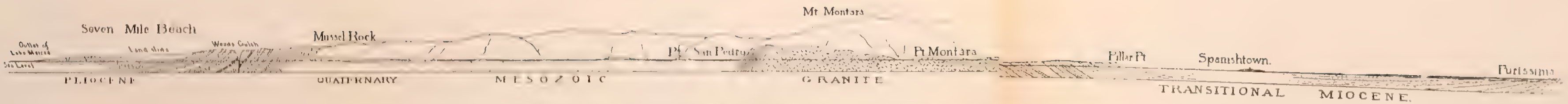
Occurrence.—The Monterey series is practically lacking on the northeastern side of the Santa Cruz Mountains. It is abundant all over the southwestern side from Spanishtown southward, and in fact all through the ranges to the south down into southern California, while similar strata have been found as far north as Oregon.

Relations.—The Monterey series, though containing but few fossils, has been recognized from the first as Miocene. Characteristic fossils are *Pecten peckhami*, Gabb; *Tellina congesta*, Conrad; *Meretrix traskii*, Conrad; *Mercenaria perlaminosa*, Conrad. A comparison of the structure alone is sufficient to show that it lies unconformably upon the older rocks.

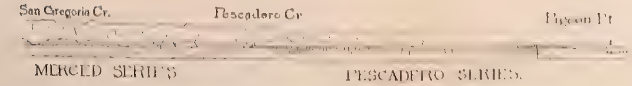
THE MERCED SERIES.

The Merced series is of considerable thickness, and is quite fossiliferous. Its location is very favorable for the exposure of fine sections, so that along the seaboard it is exposed almost continuously the whole length of the Santa Cruz Mountains and in cliffs averaging perhaps seventy-five feet high, but on Seven Mile Beach becoming over 700 feet high. (See Plate IX.)

[1] Univ. of Cal., Bull. Dept. Geol., I., 24.



Section from Lake Merced to Purissima, 23¼ miles. Vertical scale twice the horizontal scale.



Section from San Gregorio to Pigeon Point, 8 miles.
Vertical scale twice the horizontal scale.

Section from Santa Cruz to Capitola, 5 miles.
Vertical scale twice the horizontal scale.

Lithology.—The Merced series of the Santa Cruz Mountains is composed of a great thickness of partly consolidated sands, clays, argillaceous sands and hard fine conglomerates. The most abundant and characteristic rock is a dark drab or slate-colored argillaceous sand, breaking into small fragments of about half an inch cube, frequently with bright red or yellow faces. It varies in hardness from that which crushes easily in the hand to more argillaceous varieties which are tough like clay. A soft yellow or buff-colored sand is quite common, and along Seven Mile Beach there are many thin layers of hard conglomerate, usually containing many fragments of shells. Occasionally shells are so abundant as to form shell breccia.

Near the top of the section on Seven Mile Beach the strata become more and more unconsolidated and sandy, the upper layers consisting almost entirely of soft yellow and orange-colored sand. Near the top is a soft, white, chalky layer, from one to six feet thick, which Dr. Lawson considers a volcanic ash.[1]

Stratigraphy.—The section along Seven Mile Beach has a thickness of about 4500 feet; it is not complete, however, but is cut off at the bottom and south end by the great fault which runs from Mussel Rock to Black Mountain. The lower or Transition beds are exposed south of Half Moon Bay, but no way of connecting them with the Seven Mile Beach section was found. Near San Gregorio about 500 feet of strata is exposed.

Distribution.—The Merced series, antedating as it does the upheaval which gives the Santa Cruz Mountains its present topographic position, was probably originally laid down over all or most of the region now occupied by these mountains. Pleistocene movements have preserved the lower deposits, while erosion has removed the strata from the upper parts of the range.

It seems possible that most of the beds in different parts of the state from which older Pliocene fossils have been reported will be found to correspond with this series. Dr. Lawson believes that the one he recently described as the "Wild Cat

[1] Univ. of Cal., Bull. Dept. Geol., I., 144.

Series"[1] in Humboldt county may be correlated with the Merced series. Thus the fauna reported from Kirker's Pass and Green Valley, Contra Costa county, Santa Rosa and Russian River, Sonoma county, suggests the presence of the Merced series. The formation is fairly well developed at San Fernando, Los Angeles county.

Relations.—Near Santa Cruz the Merced series overlies conformably the Monterey series; the two formations seem to grade into each other at the contact. At a number of places the Merced series lies directly upon the pre-Monterey formation. This may have been due either to transgression of the sea during the Merced period or to erosion during part of one or during both of these periods.

Structure.—The end of the Monterey-Merced period was followed by the movement which elevated the Santa Cruz Mountains, making them again a prominent topographic feature. This movement was largely of the nature of faulting, and the largest fault noticed was the compound one, beginning at Mussel Rock and extending southeast nearly to Black Mountain. Many small faults were noticed; among these the one at Wood's Gulch on Seven Mile Beach has a displacement of nearly 900 feet. These faults have a strike of about southeast and northwest. Another group has the strike nearly due east and west.

As a rule the structure of the Merced and Monterey series shows only gentle folding, but locally, as on Seven Mile Beach and in that neighborhood, the dip becomes almost vertical. The structure along Seven Mile Beach reveals a great monocline, with the dip to the northeast. The other limb of the monocline is to the south in the long exposure at Pillar Point. Thence southward the structure shows gentle undulations until Pescadero Creek is reached. At Point New Year and at Capitola synclines show the presence of the Transition beds of the Merced series.

Correlation.—The Transition beds were principally noted along the coast from Spanishtown southward; also near Stanford

[1]Univ. of Cal., Bull. Dept. Geol., I., 255.

University, and in the ridge through which is cut the San Fernando tunnel in Los Angeles county.

Fifty-two species of fossils were found in the coast area of which eighteen are not known living, and four are not known in the present fauna of the same region. Using the old method of percentages we find 56 per cent. of the fossil fauna in the living fauna. It is found that twenty-two of the forms have been found in strata whose Miocene age is not questioned, of which number five are strictly Miocene. This would place these strata, according to some authorities, in the lower Pliocene; according to others, in the Upper Miocene. We do not as yet feel safe in asserting the identity of any of these species with those found in the Atlantic Miocene. In many cases, however, the resemblance is so strong that for all practical purposes we may assume them to be of the same type, and use them as though we felt sure of their specific identity.

The strata, like the Atlantic Miocene, are characterized by many huge Pectens, large Arcas, and other forms which have no representatives in the present waters of the coast. Thus, there is on the coast of California one very small species of *Arca*, found at San Diego. In these strata we find great numbers of several species of *Arca*, some of which are over four inches broad. The most common of these, the *Arca microdonta*, Conrad, will fit the figure and description of *Arca arata*, Say, of the Maryland Miocene just as well as it does Conrad's figure and description of the west coast species. The presence of the large Pectens, six or seven inches across, gives the fauna a strong resemblance to the Atlantic Miocene of Virginia and Maryland. Aside from the above localities these Pectens have been previously reported only from strata generally recognized as Miocene. The *Crepidula grandis*, Midd, is another form about four times as large as any of its living representatives. Many other interesting forms might be mentioned. It is thus seen that the fauna, while closely related to the living fauna, as shown by the percentages given above, has quite a number of species closely resembling species which, in eastern America, are typical of the Miocene.

In the area near Stanford University the percentage is still lower; out of twenty-five species found only 44 per cent. belong to the living fauna.

On Seven Mile Beach the great thickness of strata gives a good opportunity for the study of faunal changes. Thus the large *Pectens* are limited to the bottom of the series. Of the forms obtained on Seven Mile Beach, *Neptunea tabulata*, *Calyptræa filosa* and *Crepidula prærupta* occur only at the bottom of the section. *Crepidula grandis*, *Arca microdonta*, *Cardium meekianum*, *Saxidomus gibbosus*, *Mactra* (not *Venus*) *pajaroensis* and *Scutella interlineata* disappear at different horizons in about the order named, and are replaced in the uppermost layers by living forms. Thus, for example, the living *Echinarachnius excentricus* replaces *Scutella interlineata*; *Cardium corbis* replaces *C. meekianum* from which it probably descended.

Of the forms collected on Seven Mile Beach, not including the uppermost beds, thirty-two species have been identified. Of these nine are not known to be living, and five are found only in some other district. Out of thirty-two species in the fossil fauna this gives eighteen, or 57 per cent., in the present fauna of the same region. The character of the fauna is noticeably southern.

The suggestion has been made that the top of the Merced series on Seven Mile Beach extends into the Pleistocene, the fossiliferous strata above what has been called the "upper gasteropod bed" especially having a Pleistocene aspect, as all the forms found in these are still living on the coast. The whole fauna, including the "upper gasteropod bed," gave 81 per cent. of the fossil fauna living in that region.

Not only does the fauna suggest that these upper beds might be considered by themselves, but the structural relations to the lower beds is just obscure enough to prevent a positive assertion that they are conformable. The first writers on the subject regarded them as conformable.

Dynamic movements during the Tertiary.— At the beginning of the Tertiary all the region about the Bay of San Francisco seems to have been slowly sinking and steadily receiving sediment.

This continued until the Miocene. Then the great thickness of sediment yielded to mountain-forming forces. Geologically speaking this movement seems to have been quite rapid, if we may judge from the thorough way that the rocks have been folded, broken and crushed. For a time subaërial erosion was the principal dynamic factor at work in the area of the mountains. Then a slow subsidence set in, and the white shale of the Monterey series was deposited on the coast side of the mountains. In some places what is now the crest of the mountains was covered by the white shale. Then the sediment became sandy, the old mountains which had meanwhile been much eroded settled still more, and the Merced series was laid down. Near San Francisco the conditions were favorable for rapid sedimentation, and nearly a mile of thickness was laid down. Finally at the end of the Pliocene, or beginning of the Pleistocene, movement began along the old axis. Great faults were formed and the center of the range rose, not to its present height, but to a position probably about 1000–1200 feet lower. This left the present flanks of the mountains under water, a fact which doubtless accounts for the preservation there of the soft Merced series.

II. THE PLEISTOCENE HISTORY OF SAN FRANCISCO PENINSULA.

Topography.—The main portion of San Francisco peninsula is occupied by the northern end of the Santa Cruz Mountains and their foothills. The strike of these mountains to the northwest carries them to the seaboard a few miles south of the Golden Gate. In the southern part of the peninsula the mountains are separated from the bay by a broad plain. At the northern end this plain, narrowed down to a valley or windgap of some breadth, separates the mountains from the San Bruno Mountains, a parallel range only a few miles long, and from the irregular groups of hills in the city of San Francisco. On the ocean side of the mountains are remnants of a similar plain. These plains on both sides of the mountains are one of the most marked features of the topography. They usually start quite abruptly from the

steeply sloping foothills, at levels varying from 100 to 200 feet above sea level and slope gently toward the bay or sea. On the bay side these extend to the water's edge, and then are continued without change of grade to the center of the bay, then rise as slowly on the other side. On the ocean side wave action has generally cut away the lower part of the slope, leaving cliffs from ten to one hundred feet in height.

Where the contact between this level stretch and the foothills is not parallel with the shore-line or main axis of the mountains it is noticed that the elevation of the contact rises toward the axis of the mountains. In some cases this level seems to be carried up small streams nearly, if not quite, to their heads, forming a marked bench on either bank down through which the streams have recently cut. As some question has been raised as to whether these terraces are not the results of erosion rather than of sedimentation, it may be well to call attention to the evidence more in detail. In the first place, these terraces and fillings show only horizontal bedding; further, the bedding of the strata forming the hillsides is in nearly every case more or less highly inclined; and, finally, in nearly every ravine one or more contacts were found where the horizontal strata can be clearly seen lying upon the highly inclined strata of the Merced series. A few of these might be mentioned. In the head of Wood's Gulch and in the ravine which heads near it a few yards below the Old San Pedro-Colma road, the Merced sandstones and thin-bedded gravels have an almost perpendicular dip. On the edges of these perpendicular beds lie the horizontal Quaternary strata, which may be traced continuously down the ravine to a point near the crossing of the New San Pedro-Colma road; here are found many horizontal pines imbedded in the strata. In the cut just north of the Happy Valley House the horizontal Pleistocene overlies strata of the Merced series, having a dip of 35° N. 20° E.

A study of the neighborhood of San Francisco Bay points to a recent elevation of the mountains to a level much higher than their present. Such a study, as recently pointed out by Professor

Lawson,[1] shows the strong resemblance of San Francisco Bay, of Rodeo Lagoon, Tomales Bay, Walker's Creek, Drake's Bay, Ballenas Bay, the Valley of Lake Merced, etc., to sunken and submerged valleys.

There is another topographic feature which must not be overlooked. Standing upon the hills near South San Francisco station where a comprehensive view can be obtained of the line of hills extending from Seven Mile Beach to Redwood City, their summits can be seen to present a remarkably even horizontal line. Examined on the ground the top of this line of hills has the aspect of a dissected plateau, from which rise a few sharply conical knobs. These have the appearance of remnants left by the eroding waters which planed off the top of the hills.

Dr. Lawson has also pointed out that the whole coast has recently stood for a considerable time at an elevation of 1600 to 2100 feet below its present level.[2] Evidence of this is seen in the level summit of the main ridge to the north of Black Mountains.

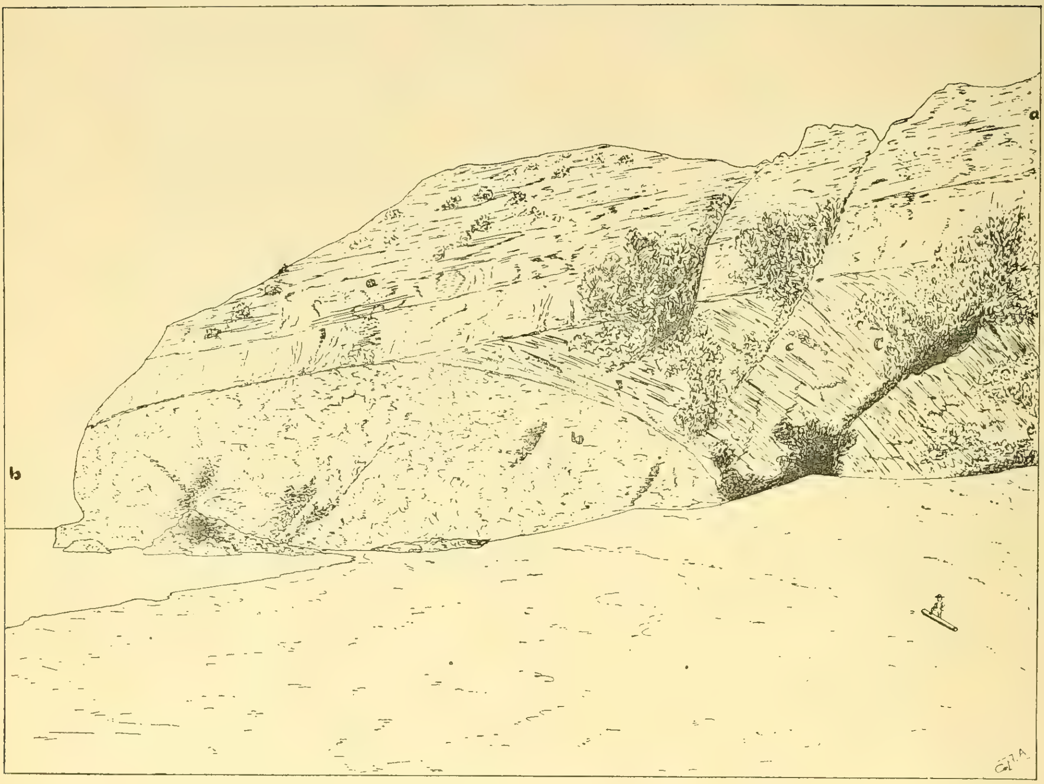
The deposits.—Turning to the deposits we find three distinct sets exclusive of those now forming.

Of the first only remnants remain. They are the deposits corresponding with the topographic features last mentioned. All along the level summit of the foothills no deposits are noticed until Black Mountain is approached; then the summits of the foothills are more or less covered with water-worn bowlders of metamorphic rocks. Bowlders do not occur further north, probably because in that direction the foothills are separated from the main ridge of the mountains by the long deep valleys of Bear Creek, Crystal Springs, and San Andreas, while near Black Mountain the foothills are connected with the mountains which must have supplied all such material.

The second class of deposits are stream and wind deposits. These are quite prominent in the benches in the streams. They appear as sand dunes on the ocean side of the mountains buried

[1] Univ. of Cal., Bull. Dept. of Geol., I., 263.

[2] Univ. of Cal., Bull. Dept. Geol., I., 115–160.



Mussel Rock from the South, showing marine Pleistocene (*a*), overlying sand dunes (*c*), and igneous rocks (*b*).

below marine deposits of later date. (See Plate X.) They make up a considerable portion of the level plain surrounding the bay as shown by recent stream cuttings. These deposits have yielded remains of the mammoth or mastodon, and in the deposits in the various streams running to the bay are found a large number of trunks and cones of conifers, sometimes four feet in diameter.

The third class are recent marine deposits. On the ocean side these are very marked, forming the top of the level benches described and having a thickness in the sea-cliffs of from five to fifty feet, in one place just south of Mussel Rock, having a thickness of over 200 feet. In some places, as near Monterey lighthouse, the beds are only a foot or two thick, and are made up of black earth, rocks, and abalone shells in great numbers. On the bay side of the mountains the surface of the broad valley plain and stream benches is the result of marine erosion and deposition. The deposits there are seldom more than a foot or two thick. Here are also found large areas of black earth full of rocks and shells.

History.—The interpretation of these data would seem to be as follows:

1. A period of erosion with the mountains about 1800 feet below their present level. This may have been the final position of the mountains at the end of the post-Merced movement, or the mountains may have shifted to this position soon after. During this time the most of the soft Merced series above the water line seems to have been removed, the water acting as a protection to the deposits which now fringe the base of the mountains.

2. A period during which the mountains stood about 1200 feet higher than during the first period, or about 600 feet below their present level. This produced the marked bench or plateau forming the summit of the foothills.

3. A period during which the region stood, according to Professor Lawson,[1] nearly 400 feet higher than at present. San Francisco Bay was a broad valley and the islands stood up as

[1] Univ. of Cal., Bull. Dept. of Geol., I., 267.

prominent hills. Conifers were abundant over parts of the area now treeless.

4. A period of subsidence. Tide-water entered the Golden Gate, filled San Francisco Bay, then spread out over the Santa Clara valley to the foothills. The whole region to the foothills was reduced by erosion and deposition to a level. The waters extended up many of the streams. San Francisco was a little cluster of islands. Considerable deposits were laid down upon the ocean-side of the peninsula.

5. A period of uplift to present level. One of the most interesting features of the last period is the remarkable erosion which has taken place in the deposits laid down in the periods just preceding. The topographic changes caused by erosion in the last twenty-five years have been so marked that, judging by the evidence of erosion in these latest beds previous to 1869, we must conclude, either that these beds have been subjected to erosion a very short time or that climatic or other conditions have become more favorable for erosion of later years. Quite a large number of hollows through which ran in 1869 county or farm roads now present impassable gullies, twenty-five to seventy-five feet deep.

III. THE AGE OF THE COAST RANGES.

A casual examination of a topographic map of California reveals a lack of unity between the northern and southern Coast Ranges as regards their strike and the apparent direction of folding. The ranges occupying the coastal region of central California have a very uniform strike of northwest and south-east, suggesting a certain unity in the time and manner of their uplift. In Santa Barbara County we come abruptly upon a series of ranges running nearly east and west through Santa Barbara, Ventura and Los Angeles counties. These ranges seem to possess a certain unity in having been elevated together. Was the movement synchronous with the elevation of the ranges further north? A comparative study of one of the ranges of each group can hardly be taken as conclusive of the groups of

ranges as a whole, but will be suggestive of what may be true of all.

The age of the Santa Cruz Mountains can with little question be placed at the end of the Merced period. Unfortunately, we are not as yet able to say exactly what is the age of the topmost beds of the Merced series. The highest beds from which fossils were obtained gave a small fauna, all of whose forms are living on the coast today, thus seeming to be of Pleistocene age. Including the fossiliferous beds which occur a few feet further down, and which must be included with the top beds, the fossil fauna shows 81 per cent. of living forms, thus seeming to be of Pliocene age. The most that can be said is that the post-Merced uplift occurred just about the end of the Pliocene or early in the Pleistocene. In either case these Coast Ranges of California are among the youngest mountain ranges of any prominence in the world.

Turning to the San Fernando Range, we find the topmost beds concerned in the uplift and folding of the range correspond with the lower or transitional beds of the Merced period, thus placing their age about the end of the Miocene or beginning of the Pliocene.

Further confirmation of this is found in a study of the horizontal fossiliferous deposits along the coast, as at Santa Barbara, San Pedro, San Diego, etc. Thus, at San Pedro in Los Angeles county, there is found first the shales of the Monterey series dipping south. Above them unconformably come first a little sand dune or wind deposit, then a few feet of quite fossiliferous sand, then a top fossiliferous layer.

The top layer is unquestionably Pleistocene. A study was made of the fossiliferous layer just below. Altogether 125–150 species were collected in this layer, of which number 104 species have been determined. Of the 104 species identified 99 or 95 per cent. are known living. But many of those living are only known now in, for example, the Arctic fauna. Thus it is found that of the 104 species twenty-six have not been reported from the coast near San Pedro, leaving seventy-eight species of 104 fossil species known to be living, or 75 per cent.

Again it is noticed that of the species which have migrated all but two have gone northward, a number being known only in Arctic waters at present.

A percentage comparison of the fauna of these beds with the present fauna of that part of the coast would make the beds Pliocene. A consideration of the Arctic character of the fauna would place them near the end of the Pliocene or the beginning of the Pleistocene. In any case they probably do not differ greatly in age from the beds which form the top of the Merced series in the Santa Cruz Mountains.

If these observations and their interpretations have been correct this will make the age of the east and west ranges of Santa Barbara, Ventura, and Los Angeles counties near the beginning of the Merced period or about the end of the Miocene; while the ranges to the north were elevated at the end of the Merced period or near the end of the Pliocene.

IV. ON THE RECENT HISTORY OF SANTA CATALINA ISLAND.

The finding of a species living which had been supposed to be extinct, or which if not extinct had long since been forced by changing conditions to migrate to some other region, has always had a peculiar interest to the student of biology or geology. Still more interest attaches to the finding of a fauna which belonged to a bygone age, and especially when the record of events is sufficiently clear to give a plausible reason for the presence of the older fauna. Such a condition of things seems to exist on Santa Catalina Island today.

In the preceding study attention was called to the existence at San Pedro, and other points, of beds containing an abundant fossil fauna of probably Pliocene age. The two fossiliferous beds at San Pedro were deposited during a submergence of all the coastal region, the lower or Pliocene beds having preceded the submergence, the upper beds having been laid near the end of the elevation which followed. This movement shows most clearly in the topographic features of the coastal region of southern California. Everywhere near the coast is evidence of a

recent submergence to a depth of from 1200 to 1500 feet. The long stretches of plains and level benches, the old cliffs marking the advance of wave action, the stream topography which within those levels seems to be just taking a new start, are all evidence of the same fact.

Santa Catalina Island is a large island lying about twenty miles south of San Pedro. A short time since Professor Lawson called attention to the fact that Santa Catalina Island had not shared in the general depression which had submerged the other islands and coastal regions.[1] He pointed out that the island shows no shore lines, no benches, no levels of erosion. The stream basins are all of considerable age, having deep, rugged valleys, and the sharp edges of the separating ridges are typical of subaërial erosion long continued.

We find, then, that the conditions have remained constant here since the time when the Pliocene beds were being deposited over on the mainland. It will be of interest then to compare the present fauna of Santa Catalina Island with the fauna living now on the coast of San Pedro, and also with the fossil fauna found at the same place.

By a study of Dr. Cooper's list of Californian fossils, 1888, we find that five otherwise extinct species from the Pliocene or Quaternary of Santa Barbara, San Pedro, and San Diego are still living on the island: *Amycla undata*, Carpenter; *Daphnella clathrata*, Gabb; *Nassa insculpta*, Carpenter; *Psephis salmonea*, Carpenter; *Solarellia peramabilis*, Carpenter. There are also found living on the island, and fossil on the mainland, one species, *Cryptodon flexuosus*, Montagu, known elsewhere only in the North Atlantic; one, *Lucina borealis*, Linnaeus, known elsewhere only in Arctic waters; one, *Laqueus californicus*, Koch, known elsewhere only in the North Pacific. In addition to these, thirteen species — *Bittium asperum*, Gabb; *Callista newcombiana*, Gabb; *Cardium centifilosum*, Carpenter; *Chrysodomus tabulatus*, Baird; *Diala acuta*, Carpenter; *Leptothyra bacula*, Carpenter; *Lucina tenuisculpta*, Carpenter; *Lunatia pallida*, Broderip and Sowerby;

[1] Univ. of Cal., Bull. Dept. Geol., I., 138.

Margarita pupilla, Gould—which are found on or about Santa Catalina Island are only known elsewhere on the coast to the north; while it forms the northern limit of four species, *Chorus belcheri*, Hinds; *Nucula exigua*, Sowerby; *Omphalius fuscescens*, Philippi; *Ostrea conchaphila*, Carpenter.

These facts indicate that fauna of Catalina Island has been little affected during a time when many species on the mainland have become extinct and others forced to migrate. The fauna is largely northern, though possessing a few southern forms. It thus resembles quite strongly the fauna studied at San Pedro and called in this paper Pliocene.

This case is interesting, not alone from showing that the fauna considered Pliocene on the coast of the mainland is still living on or about the island, but from the way the deductions made from the topography and from the fauna support each other.

GEORGE H. ASHLEY.

STOCKTON, CAL.,
April 6, 1895.

SOME CRETACEOUS BEDS OF ROGUE RIVER VALLEY OREGON.

CONTENTS.

INTRODUCTION.

In the summer of 1894 a large part of the months of June and July was spent by the writer in studying the Cretaceous beds of southern Oregon.[1] The deposits most thoroughly worked lie in the portion of Rogue River Valley west and southwest of Jacksonville, extending to the summit of the Siskiyous where these are crossed by the Oregon and California Railway. This region is more strictly an arm of what is commonly known as Rogue River Valley, and may, for the purpose of the present paper, better be called the Bear Creek Valley. Its general direction is northwest and southeast. It lies between the high granitic ridges of the Siskiyous on the southwest and the southern portion of the Cascade range on the east. The upper portion of the valley, near where the railway crosses the summit, is not far from the point where the Siskiyous join the Cascades. From this point the valley widens gracefully into the deep basin,

[1] The data obtained were studied at the laboratory of Stanford University, where much of the material collected is preserved.

into which one may look down from the cars when near the little station of Siskiyou. Two or three miles below the town of Ashland some granitic ridges from the south come down abruptly to the creek, almost severing this upper portion of the valley from the main valley beyond. West and northwest of these ridges the valley expands again until, in the vicinity of Medford, its width is from eight to ten miles, while from this point to the summit just mentioned the distance is something like twenty-five miles. In this valley the Cretaceous beds appear mainly on the eastern side, or on the side east of Bear Creek, and probably also occupy the floor of the valley where they are overlain by Pleistocene deposits.

It has been thought that these beds, which are of Upper Cretaceous or Chico age, extend indefinitely eastward under the lavas of the Cascades.[1] It cannot be said, however, that the facts observed during this study confirm this opinion. On the contrary, the true relation of the sedimentary rocks here described to the rocks of the Cascades is so apparent and so uniform that one cannot fail to be convinced that at least this portion of the Cascade range is older than the Chico portion of the Cretaceous.

PRE-CRETACEOUS.

Underlying the Cretaceous are three distinct series of rocks which may be called the granite series (including the schists), the basalt series and the slate series. The point of junction between these series is probably not far from the town of Talent; and from this point lines separating approximately the three pre-Cretaceous series may be drawn as follows: Toward the southeast the general course of Bear Creek, or, still better, an irregular line between that and the line of the railway divides the granite on the west from the basalt on the east; toward the southwest the line separating the granite on the south from the slates on the northwest follows the course of Wagner Creek southward for a mile or more, then swings toward the west and

[1] Geol. Sur. Cal., Vol. I., p. 354. Seventh An. Rep. U. S. Geol. Sur., p. 98. U. S. Geol. Sur., Bull. 33, p. 20.

follows the upper portion of Anderson Creek to its head; from Talent the line between the slates on the west, and the basalt on the east, runs in a northerly direction.

Each region and each series has its own distinguishing characteristics. The rocks of the granite series are made up of massive granites and of folded and contorted schists. No attempt was made to separate these in working out the areal geology. The peaks and ridges of this area are high and rugged, and the canyons are deep and generally heavily timbered with spruce and pine.

The slates, which are no doubt a northward continuation of the auriferous slates of California, portions of which they closely resemble, are variable in character. In some places they are dark, fine grained and argillaceous; in other places they are micaceous, talcose or shaley with large masses of quartzite. Where they are auriferous they often contain numerous small and irregular veins of quartz. The mountains of the slate area are less rugged, often low and less heavily timbered than those of the granite area.

The area of basaltic rocks is also well characterized by regular and rolling hills which are generally not deeply eroded, and in which the rocks seem to be more uniform. These basaltic hills form the western edge of the Cascade range at this point. For the most part they consist of old basalts, andesites and other basic eruptives.[1]

Upon each of these series of rocks the Cretaceous strata rest with equal distinctness, and with equal absence of metamorphism, or alteration, other than what would be expected from weathering. The only case of alteration that was observed in these rocks is in the immediate vicinity of dikes of limited extent, which have made their way through the strata at various places, often without disturbing the regular position of the beds. In such cases the alteration is confined to a few feet or yards on each side of the intruding mass. As far as is known the dikes occur mostly along the line of junction between the granite and the basalt.

[1] Seventh An. Rep. U. S. Geol. Sur., p. 98.

CRETACEOUS.

Transgression.—It has been pointed out by Mr. J. S. Diller[1] that in the region of northern California and southern Oregon, during the deposition of the Cretaceous strata, a gradual subsidence of the land carried the eastern shore-line inland. In California this transgression of the sea was toward the northeast, while in southern Oregon it was generally toward the southeast. The facts observed in that portion of Rogue River Valley under discussion may conform to this rule in the main, but being in the more immediate neighborhood of the Siskiyous, they may indicate, also, a subsequent elevation of this range relative to the Cascades. The strata consist of heavy beds of conglomerates, shales, and sandstones which generally dip toward the northeast at an angle varying from 10° to 30°.

The fauna of the Cretaceous at Riddles, Douglas county, Oregon, which is about sixty miles to the northwest, shows a much lower horizon for those beds than is indicated by any fossils yet found in this valley. Deposition was therefore going on at Riddles before the Rogue River Valley was submerged.

STRATIGRAPHY OF THE CRETACEOUS.

As the strata generally dip toward the north, away from the granites of the Siskiyous, as shown by the accompanying sections, the lower and older strata appear along the western flank of the valley. However, for the most part the strata are destitute of fossils. This remark applies to the upper beds which occupy the eastern side of the valley, but which, from their lithology, dip, etc., are known to be conformable and continuous with the fossiliferous beds to the west. They are probably equivalent to the barren Chico beds of northern California. Thus far fossils have been found only along the western side of the valley; though along this side, from the summit where the railway crosses, northwestwardly to Jacksonville, fossils are rather abundant. Three localities, besides the two mentioned by Gabb, have furnished fossils of a varied and interesting character.

[1] Bull. Geol. Soc. Am., V., 452.

Ashland locality.—About four miles south of Ashland, near the railway, the following species have been collected:

Pachydiscus aff. denisonianum, Stol.	Cucullæa truncata, Gabb.
Cinulia obliqua, Gabb.	Chione varians, Gabb.
Fasciolaria rigida, Bailey.	Cyprimeria lens, Gabb.
Gyrodes pansus, Stol.	Homomya concentrica, Gabb.
Pugnellus manubriatus, Gabb.	

This indicates an upper horizon for these beds, but not the uppermost Chico. The beds here are of a grayish, or light-colored sandstone, dipping toward the east at an angle of about 30°. A short distance to the south, where the sandstone is quarried on the east side of the railway, the beds are thicker and of a light grayish color; they also dip toward the east at about the same angle.

Griffin Creek.—Collections made at a second locality on Griffin Creek. a few miles east of Jacksonville, contain the following species:

Trigonia leana, Gabb.	Exogyra, sp.
T. tryoniana, Gabb (?).	Inoceramus, sp.

Here the beds are of a tawny or grayish sandstone, and dip at an angle of 20° toward the west and northwest. These strata, as at Jacksonville, a few miles to the west, rest upon the highly tilted or folded auriferous slates. The fossils indicate a horizon a very little lower than the beds near Ashland.

'49–Mines.—A third locality, at which the largest and most interesting collection was made, is one and one-half miles southwest of the town of Phœnix, at the old placer mines, locally known as the '49-Mines. Here also the Cretaceous beds consist of conglomerates, yellow shales, and sandstones, resting upon the auriferous slates and dipping toward the northeast at an angle of 30°. The fossils collected at this point show these beds to be somewhat lower than those before mentioned, although some of the fossils belong to the upper Chico of the California Cretaceous. The following is a list of the fossils identified from this locality:

Acanthoceras, aff. naviculare, Mant.
Pachydiscus, aff. denisonianus, Stol.
Gaudryceras, aff. timotheanum, Mayor.
Lytoceras, conf. jukesi (Sharpe)—— Whiteaves.
Phylloceras ramosum, Meek.
Scaphites, sp. a.
Scaphites, sp. b.
Schloenbachia chicoensis (Trask) Gabb
Schloenbachia inflata, Sow.
Schloenbachia propinqua, Stol.
Schloenbachia, conf. serrato-carinata, Stol.
Schloenbachia, sp.
Nautilus, aff. rota, Blanford.
Baculites, sp.
Hamites, sp.
Heteroceras, sp.
Actæonina californica, Gabb.
Anchura californica, Gabb.
Anchura falciformis, Gabb.
Cinulia obliqua, Gabb.
Cinulia, sp.
Dentalium stramineum, Gabb.
Euspira, aff. pagoda, Forbes.
Fulgur hilgardi, White.
Fulguraria gabbi, White.
Globichoncha remondi, Gabb.
Gyrodes conradiana, Gabb.
Gyrodes pansus, Stol.
Gyrodes, sp.
Margaritella globosa, Gabb.
Avicula nitida, Forbes.
Cardium remondianum, Gabb.
Chione varians, Gabb.
Cucullæa truncata, Gabb.
Cyprimeria lens, Gabb.
Exogyra, sp.
Exogyra, sp.
Homomya concentrica, Gabb.
Inoceramus labiatus, Schloth.
Inoceramus, sp. a.
Inoceramus, sp. b.
Meretrix nitida, Gabb.
Modiola siskiyouensis, Gabb.
Ostrea, sp.
Pectunculus veatchi, Gabb.
Pectunculus sagittata (?), Gabb.
Pinna breweri, Gabb.
Tellina parilis, Gabb.
Teredo, sp.
Trigonia evansana, Meek.

STRUCTURE.

Sections.—The section shown in Fig. 1 is approximately in the direction of the dip drawn through the vicinity of the '49-Mines in a northeasterly direction. Toward the western end, as has been said, the Cretaceous strata rest directly upon the auriferous slates, and dip more nearly toward the north, at an angle of 30°. In the bottom of the valley they are covered by Pleistocene deposits, but appear again where the erosion of Bear Creek has exposed them. From this point, one travels across the upturned edges of the beds to near the summit of the mountain. The dip is pretty uniform for the greater part of the section, but toward the eastern end it is somewhat less steep.

Just east of Bear Creek the first low range of hills is formed

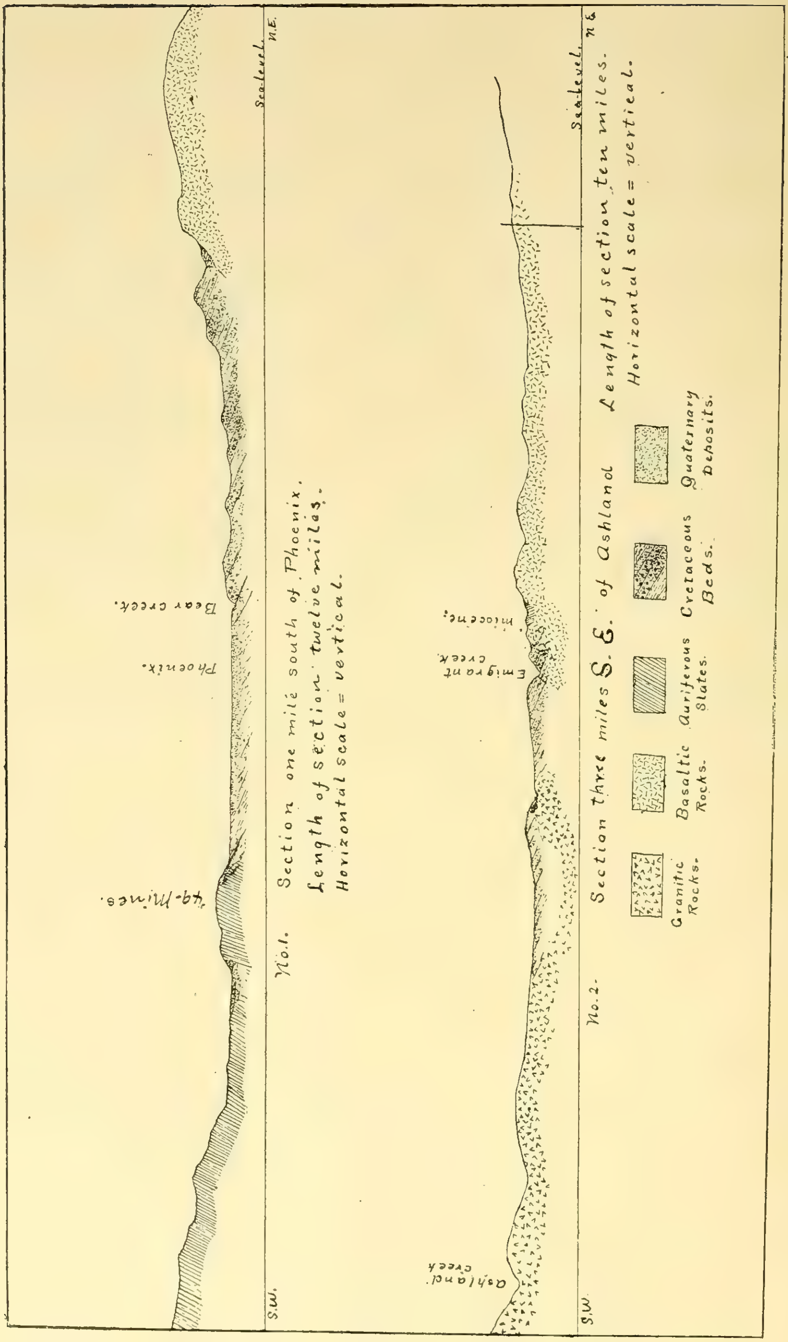
mainly of a coarse pebbly conglomerate, the material of which is of doubtful origin, many of the larger pebbles being quartzose and much worn and rounded. These are succeeded by soft, yellow shales, with sandy layers, and these again by pebbly sandstone, until near the eastern extremity of the section where the strata consist of more massive sandstone with a somewhat gentler dip. These sandstones rest directly upon the old eruptives that form this spur of the Cascades. The contact, which is distinct in numerous places, shows no signs of alteration in the sandstone resulting from their contact with the lavas, nor are the lavas anywhere found resting upon the Cretaceous rocks.

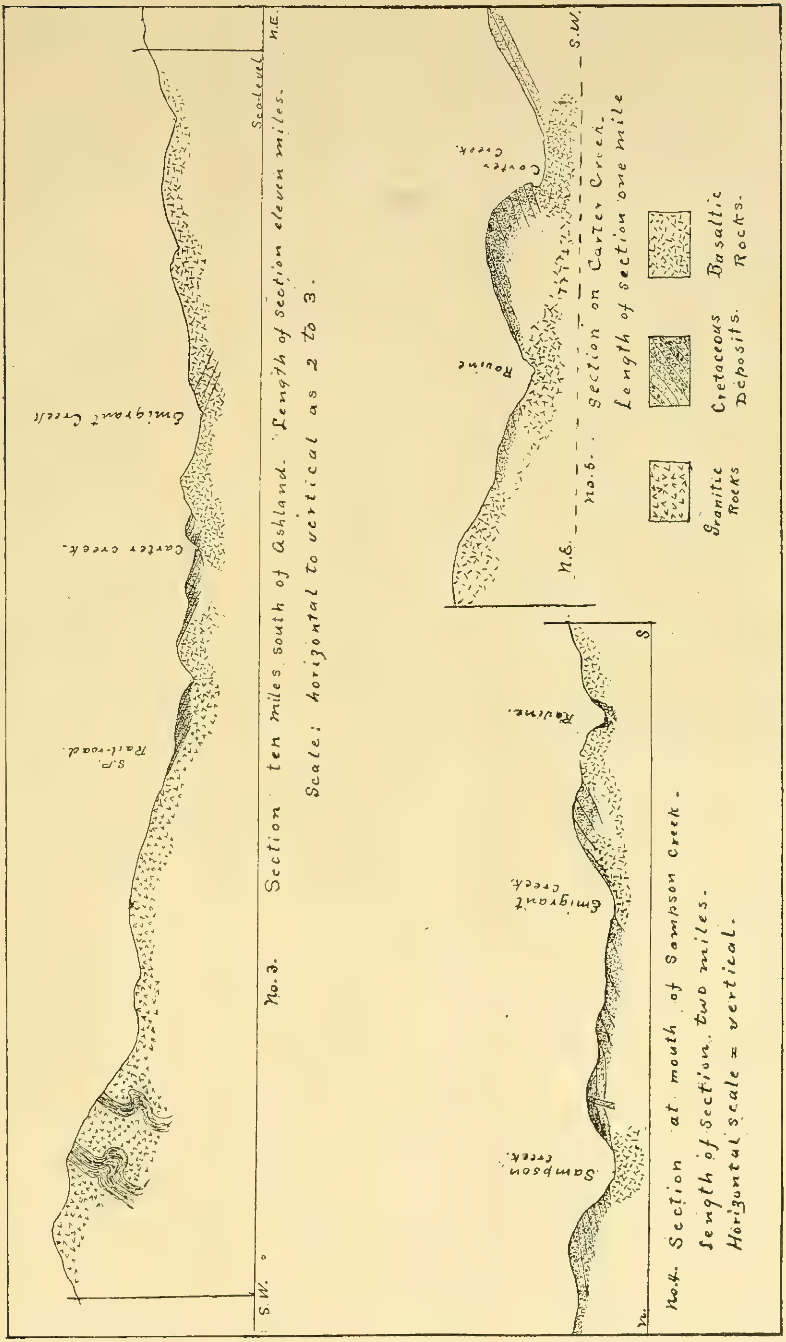
Figure 2 shows a section drawn in a northeasterly direction through the locality at which fossils were found four miles south of Ashland. This locality is at the western extremity of this section. Here the Cretaceous beds rest upon the granite of the adjoining ridge from which they dip away at an angle of 30°.

In the bottom of the valley the granite again emerges from beneath the sedimentary rocks, and is replaced at Emigrant Creek by the pre-Cretaceous lavas upon which the Cretaceous strata rest along the sides of the mountain. Farther up the mountain toward the east the lavas again make their appearance, and continue toward the summit without interruption; but a few hundred yards above the limit of the Cretaceous beds they (the lavas) are covered for a short distance by a remnant of white Miocene shale, apparently of fresh-water origin. These shales contain an abundance of fossil plants, some species of which were identified by F. H. Knowlton, as follows:

Myrica langeana (?), Heer.	Alnus corralina, Lx.
Sequoia langsdorfii, Brgt.	Quercus lonchitis, Ung.
Lastræa fischeri, Heer.	Quercus n. sp.
Planera, sp.	Andromeda, sp.

Still farther toward the south, in the vicinity of Wagner's Soda Springs, the Cretaceous beds have the same general dip of 30° to the northeast and bear the same relation to the granite on the west and to the old eruptions on the east (see section in Fig. 3). Toward the western end of the section the


S.W.
N.E.
Sealevel.
Bear creek.
Phoenix.
'49-Mines.
No. 1. Section one mile south of Phoenix.
Length of section twelve miles.
Horizontal scale = vertical.
S.W.
N.E.
Sealevel.
Miocene.
Emigrant creek.
Ashland creek
No. 2. Section three miles S. E. of Ashland Length of section ten miles.
Horizontal scale = vertical.
Granitic Rocks.
Basaltic Rocks.
Auriferous Slates.
Cretaceous Beds.
Quaternary Deposits.


No. 3. Section ten miles south of Ashland. Length of section eleven miles.
Scale: horizontal to vertical as 2 to 3.
S.W.
N.E.
Sea-level
Emigrant Creek
Carter creek.
S.P. Rail-road.
No. 5. Section on Carter Creek.
Length of section one mile
N.E.
S.W.
Carter Creek.
Ravine
Granitic Rocks
Cretaceous Deposits.
Basaltic Rocks.
No. 4. Section at mouth of Sampson Creek.
Length of Section two miles.
Horizontal scale = vertical.
N.
S
Sampson creek.
Emigrant creek.
Ravine.

Cretaceous sandstone rests directly upon and covers the granite, which, however, makes its appearance again in the bottom of a deep ravine a few hundred yards to the east. The basic rocks come to the surface almost in contact with the granite and continue to the summit of the low ridge eastward, where they are covered by the Cretaceous sandstones. These sandstones extend from this point for a distance of a mile or more; beneath them the igneous rocks again appear in the canyon of Carter Creek. From this place they continue eastward indefinitely.

Figures 4 and 5 represent, on a larger scale, some sections at points in the vicinity of Wagner's Soda Springs.

Figure 4 is a north-south section across Sampson Creek a short distance from its mouth. The sides of the canyon are of Cretaceous sandstone, which has been eroded by the stream down to the older basic rocks which here underlie it.

Figure 5 is a northeast-southwest section across Carter Creek one mile north of Smith's Soda Springs. In the bed and on both banks of the creek the rocks are the basic eruptives which, at twenty feet from the stream, on the east bank, show clearly their contact with the sandstones which project over them. These sandstones form the whole of the ridge toward the east, until, in the bottom of the next ravine, half a mile to the northeast, the older lavas again make their appearance.

Thickness of the beds.—It is not easy to say what the original thickness of these beds has been, but the estimated thickness of those remaining is between ten thousand and fifteen thousand feet.

Coal beds.—At various places along the eastern side of the valley small beds of coal are occasionally found. They are the mere remnants of beds once more extensive; they are thin and of no economic importance.

Faults.—Although in some of the accompanying sections there is a suggestion of faulting along the line of Bear Creek, there is no evidence that this is the case. The strata have a uniform dip on both sides of the valley, and those found along the western side are nowhere represented on the eastern. No fossils

except plants have been found east of Bear Creek. The sedimentation was apparently continuous, and the beds are unbroken along the whole length of the section.

Subsidence.—As far as is known all the beds of this region are of younger age than those at Riddles, Douglas county, farther to the northwest, which have been described by Mr. Diller and Mr. Stanton,[1] and which seem to be of Upper Knoxville age. This, as they have shown, indicates a general subsidence of the land toward the southeast.

Elevation.—Glancing again at the accompanying sections, it seems remarkable that the steep and uniform dip of the strata can be accounted for by a subsidence of the land along the eastern shore-line. On the flanks of the Siskiyous, notably near the railway tunnel at the summit, at an elevation of 4000 feet, fossils are found which indicate a lower horizon than that of the barren sandstones upon the basaltic area a few miles to the northeast, at a much lower elevation. The Miocene strata known in this region also dip at a high angle away from the granite of the Siskiyous, which would not be expected without some movement subsequent to their deposition. This elevation, then, probably took place about the time of the general outpouring of the lava which covers eastern Oregon from the Columbia River south, and northern California. This lava, as has been shown by Professor Le Conte and others, is later than the Miocene.[2]

NOTES ON THE FOSSILS.

Horizon.—Although the fossils collected near Phœnix were all obtained from an area of less than one hundred feet square, it is not clear that they are all from the same horizon. A glance at the section, Fig. 1, will show that an immense thickness of strata has been removed at the locality at which the fossils were found. The fossils may not all have been in their original places, as they were found mainly in blocks of hard rock resting irregularly upon

[1] Bull. Geol. Soc. Am., V., 452.

[2] Am. Jour. Sci., VII., 1874, 176. Geol. Sur. Cal., I., 354. U. S. Geol. Sur. Bull., No. 33, 20.

a stratum of softer, yellow shale. These blocks are probably the remnants of overlying strata which have been removed. Many of the fossils, hitherto not cited from this coast, were submitted to Mr. T. W. Stanton, to whom the writer is indebted for many valuable suggestions.

Acanthoceras, conf. *naviculare*, Mant.; Geol. of Sussex, 198, t. 22; Min. Conch, p. 105, t. 555; Cret. Ceph. Ind., p. 73, pl. 39.

Two specimens of this shell were collected and, although not perfect, there can be little doubt that it is closely related to *A. navicularis*. It agrees remarkably well with Blanford's description and figure, and also the description and figure by Sharpe, with the exception of the tubercles at the umbilical end of the longer costæ. Blanford, however, remarks that these are not always present even in young specimens, in which they are usually more constant. The sutures, as far as they can be traced, leave little room to doubt the identity of this species.

Pacydiscus, aff. *denisonianus*, Stol.; Cret. Ceph. Ind., p. 133, pl. 66.

Three specimens of this ammonite were found, one of which is in good state of preservation. The only essential differences that can be seen between this shell and those described from the Cretaceous of southern India is in the slightly greater thickness, and a little wider umbilicus in older specimens of the Indian species.

Gaudryceras, sp.

Four specimens were obtained in good state of preservation, two of which are nearly two inches in diameter. While in some respects this shell resembles *G. timotheanum*, Mayor, the whorls are more rounded and not so thick. One of the smaller specimens and a fragment of another show the squarish whorls, but all of them lack the transverse furrows.

Lytoceras, conf. *jukesi?* (Sharpe), Whiteaves; Pal. Sus., V. 8, p. 53, pl. 23; Can. Mess. Foss., Vol. I., Part 2, p. 111, pl. 13.

A single, well-preserved specimen of this fossil, about one inch in diameter, was found. It agrees fairly well with Whiteaves' description referred to above, with the exception of the trans-

verse ridges. There are, however, slight markings that indicate a periodical interruption of growth.

Schloenbachia chicoensis (*?*), (Trask), Gabb; Proc. Cal. Acad. Sci., 1856, Vol. I., p. 92, pl. 2; Cal. Pal., Vol. I., p. 68, pls. 13 and 14.

A number of specimens were collected of a species closely resembling *A. chicoensis* figured by Gabb, as do also most of the specimens that I have seen from California. It is, however, doubtful if these and Dr. Trask's figures represent the same species.

Schloenbachia inflata, Sow; Min. Conch., II., 1878; Cret. Ceph. Ind., 48, pl. 28 and 29; Can. Mess. Foss., VII., I., part 3, 200.

One specimen five inches in diameter in fair state of preservation, and a large number of smaller ones of this species, varying from one-half to one and one-half inches in diameter, were obtained. The smaller ones are all well preserved.

Schloenbachia propinqua, Stol.; Cret. Ceph. Ind., 53, pl. 31; Can. Mess. Foss., II., Part 3, 247, pl. 33.

One specimen two inches in diameter and a large number of smaller ones, one-half to three-fourths inch in diameter, with numerous fragments of various sizes, all in good preservation, were collected. This fossil, with its numerous bifurcating ribs, tubercles, rounded outer margin, undoubtedly represents the species to which it is here assigned.

Schloenbachia, conf. *serrato-carinata*, Stol.; Cret. Ceph. Ind., 57, pl. 32.

A number of fossils, one-half to one and one-half inches in diameter were collected, which seem to be of this species. In most respects they agree quite well with Stoliczka's figure, but seem to be less deeply grooved along each side of the keel; yet he remarks that the grooves are not so deep as figured. In the specimens collected the keel is prominent, and in some of the specimens serrated, while in others it is not. A double row of tubercles near the outer margin ornament the ribs.

Nautilus, conf. *rota*, Blanford; Cret. Ceph. Ind., 38, pls. 24 and 25.

Two specimens of this species were found, one of which, after breaking away the outer whorl, furnished a specimen two inches in greater diameter. The edges of the septa are distinct and show the characteristic curves. It has also the closed umbilicus and narrower ventral margin and outline of *N. rota*, but is rather narrower and has not the surface markings. The larger specimen resembles *N. texanus* (*?*), (Shum), Gabb. It is possible that this species of Gabb will eventually prove to be identical with *N. rota*, Blanford.

Gyrodes pansus, Stol.; Cret. Gastr. Ind., 305, pl. 22.

Six specimens of this fossil were found all in fair preservation and two of which were exceptionally good. The characteristic markings, low spire and outline all indicate that there can be no doubt of its proper identification.

Avicula nitida, Forbes; Trans. Geol. Soc. Lond., VII., 151; Peleo. Ind., 404, pl. 24.

Six specimens were collected of this shell which show clearly all the characteristic features of the species. The fossils are all well preserved.

Inoceramus labiatus, Schloch; Bronn's Jahrb., VII., 93; Proc. Acad. Sci. Phil., 1857, 119; Can. Mes. Foss., I., part 3, 193; U. S. Geol. Sur. Bull., 106, 77, pl. 14.

Ten quite perfect half-shells, besides a large number of fragments of this species were obtained. The shells agree so well with Meek's description that there can be no room for any other reference.

Pectunculus sagittata (*?*), Gabb; Cal. Pal., I., 197, pl. 131; U. S. Geol. Sur. Bull., No. 51, 39.

A number of specimens of this shell were found in very good preservation, which resemble very closely *P. subplantata*, Stol., but being uncertain as to their identity with this species, I have preferred to refer them to *P. sagittata*, Gabb, in view of what has been said by Professor White as to the absence of the sagittate markings.

F. M. Anderson.

Stanford University,
California, May 8, 1895.

GLACIAL STUDIES IN GREENLAND. V.

THE REDCLIFF PENINSULA.

FROM the north side of the deep inlet formed jointly by Murchison Sound and Inglefield Gulf, McCormick Bay sets back to the northeast, while Bowdoin Bay, which lies to the east of it, sets back to the northwest. The result of these convergent courses is to bring the heads of the two bays near each other and to enclose a sub-triangular area whose three sides may b e roughly taken as fifteen miles in length. Between the heads of the bays the ground is low and partially occupied by lakes which gives further emphasis to the peninsular character, for the most of the area is a plateau and this low tract has the moral effect of a partial disseverance. The margin of this plateau to a width varying from a few rods to perhaps three miles is bare of ice, except as glacial tongues intrude upon it. This portion reaches about 2000 feet in height. The central portion of the plateau is covered by an ice-cap, which, according to Lieutenant Peary, mounts up to 4000 or more feet in altitude. Whether this means that the ice is 2000 feet thick or that the land beneath the ice swells upward is a matter of uncertain interpretation. The configuration of the summit favors the view that the land participates in the increased elevation to some notable degree, but the ice is obviously thick. From this ice-cap tongues creep down into the valleys on all sides of the peninsula. They even descend to the northward upon the low neck connecting the peninsula with the mainland. Two of these ice-tongues on the south, two on the east, and one on the north were examined at hand. The others were only cursorily seen at greater or less distances.

Local ice-caps while almost immeasurably inferior to the inland *mer de glace* in general interest and significance are nevertheless in certain respects not only equal but even superior to it as factors in glacial study. They define more sharply the limitations

of glacial accumulation. The occurrence of the border of the inland ice sheet at given elevations leaves us in doubt whether its presence signifies that the conditions of glaciation are there present normally, or whether the ice has simply been pushed forward to that point by the *mer de glace* back of it. Local ice-caps, on the other hand, show that the conditions of glaciation are unquestionably present. They thus enable us to determine quite accurately what elevations (under existing conditions) are adequate to produce glaciation, and to fix the limit of adequacy. So also, equal elevations being chosen as a basis of comparison, the local ice-caps furnish the means of estimating the relative influence of meteoric conditions.

The ice-cap of Redcliff peninsula is an excellent example of the plateau variety of the local type. It suffers no interruption from mountain peaks. It spreads in an unbroken sheet over the whole interior and creeps outwards in all direction. In this last feature it is felicitous in permitting, within so narrow limits, the study of glacial tongues moving toward all points of the compass.

The Fan glacier.—The most westerly of the tongues from the ice-cap of Redcliff peninsula has been designated the Fan glacier from the beautiful deployment of its lower portion.[1] It is but a lobe of the peninsular ice-cap descending a broad valley excavated in the shales and sandstones that constitute the uppermost division of the clastic series, which has been previously described. While no measurements were made, it will probably not be very far from the truth to regard its length as three miles and its breadth as falling little short of one mile. The glacier declines with a gentle and regular slope that imparts great beauty to its longitudinal profile (Fig. 23). This doubtless indicates much smoothness in the floor over which it is advancing, as well as freedom from lateral constrictions and topographic strains of all kinds. Its transverse profile, as seen from the valley in front is singularly symmetrical and graceful (Fig. 24). It is doubtful

[1] A figure of this glacier is given by Professor Angelo Heilprin in Popular Science Monthly, November 1894, p. 12.

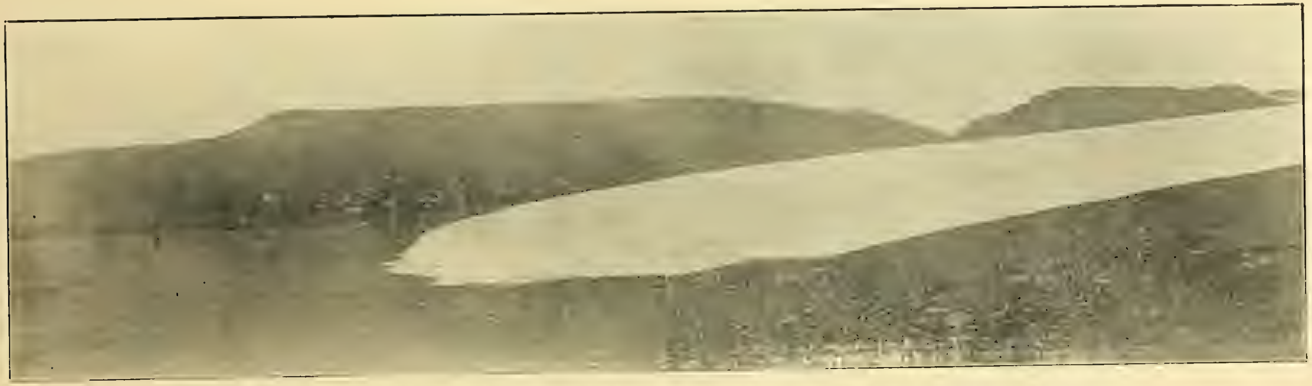


FIG. 23. Longitudinal profile of Fan glacier, from photograph by Professor William Libbey, Jr.

FIG. 24. Front view of Fan glacier, from photograph by Professor William Libbey, Jr.

whether any known glacier exceeds it in the beauty of its superficial curvatures. The foreground in the illustration shows that it is resting upon a plain formed by the deposits of its own waters, and to this its symmetry is doubtless chiefly due. It may be taken as a rare type of the behavior of ice in an exceptionally untrammeled situation under the conditions of a high northern latitude. The photographic illustrations express for themselves the angle of the slope and the law of the profile's curvature.

Next to its graceful contours the steep front invites attention. It will be observed in the figures (Figs. 23, 24, 25, 26 and 27) that at the base there is an embankment, presently to be described, above which the ice rises nearly vertically to a height about seventy-five feet above the plain. Above this there is an arching but receding brow, the curvature of which becomes more and more gentle as it retires from the face. It will be seen that the verticality of the face maintains itself throughout all its arching course across the valley, and that it is as pronounced in the center as at the sides. The verticality is obviously due neither to lateral nor to central agencies as such. It cannot be attributed merely to the reflection of rays from surrounding elevations, for there are none opposite its wide frontage. The gravel plain spreads uninterruptedly down to the gulf. It will not be wise to draw conclusions respecting the cause of this verticality of face at this point, as we shall have occasion to note the phenomenon in much more pronounced forms in a dozen or more glaciers which present various attitudes and diverse environments.

Along the base of the glacial front it will be observed that there are numerous white cones (Figs. 24, 26 and 27), and between these a sloping embankment resting against the steep face of the glacier. Rising from each of the white cones there may be seen lines which reach back across the brow of the glacier and are lost upon its upper surface. These are little channel-ways cut by streamlets formed on the surface of the glacier by its melting. As these streamlets coursed rapidly down their little channels they dislodged coarse granules of the ice, loosened by the sun, and carried them away and, precipitating them over the face

FIG. 25, Face of Fan glacier. Photo. by Prof. Wm. Libbey, Jr.

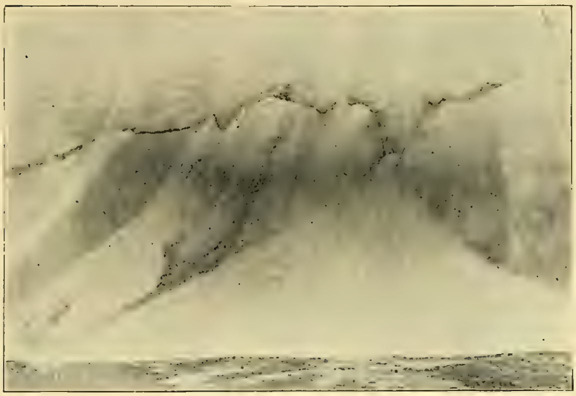


FIG. 26. Cones in front of Fan glacier. Photo. by Prof. Wm. Libbey, Jr.

FIG. 27. Terminal profile and cones of Fan glacier. Photo. by Prof. Libbey, Jr.

of the glacier, heaped them up in cones at its base. Not only was this indicated by the structure of the cones themselves, but the process of their formation was observed in actual progress.[1] Its rapidity was something surprising. As the granules were brought down the ice-wall by the cascading rivulet they occasionally struck projections and bounded forth into the air and fell upon the slopes of the cone. In other cases they were seen to leap forth from the rivulet when it struck the summit of the cone ; but in the main they simply gathered at the apex of the cone until they blocked up the little channel-way and forced the rivulet to seek another course only to be blocked in turn and thus forced to and fro, building up the cone symmetrically. The rapidity of action observed was doubtless somewhat exceptional for the day was unusually bright and warm. It is doubtful whether it was equaled by more than ten days during the entire season.

The embankment between the cones had a well developed granular structure, but it appeared to be formed in considerable part from wind-drift accumulations. It was very notably solidified into a half-ice. The surface was covered with dirt and to some extent with rocky and earthy débris that had fallen from the face of the glacier. From its solidity, dirtiness and other features it seemed scarcely possible that it was the product of the current season solely. As may be inferred from the illustrations, it lay close against the front of the ice-wall rising in some places half its height. Nowhere did I observe any disruption or crumpling of the embankment as though the glacier had crowded against it since it was formed, nor, on the other hand, it is scarcely needful to say, was there any crevasse or interval between it and the glacier, indicating a retreat of the ice. Such retreat would only be produced by the melting of the glacier backward faster than it moved on, and such melting could scarcely be supposed to take place without involving the destruction of the embankment as a concurrent, if not a prerequisite, condition. Manifestly melting could not have counteracted the onward movement at the base of

[1] PROFESSOR LIBBEY was the first to note the action in progress.

the glacier because of the protection interposed by the embankment itself. It is obvious that this phenomenon suggests, if it does not demonstrate, the inertness of the glacier at its extremity. It is difficult to see how it could be moving at any appreciable rate at its end without some disruption of the embankment, unless it be supposed that the embankment was pushed bodily forward as though a part of the glacier itself. In this case there would be reason to expect disruptive phenomena at the forward edge of the embankment, none of which was observed.

The existence of the numerous streamlets on the surface of the glacier and their size, indicating that they had run considerable courses, is an index of the freedom of the lower part of the glacier from crevasses. This freedom is in signal harmony with the smoothness of its bottom and the slowness of its motion. It is interesting in this connection to note especially that it is not longitudinally crevassed, as is the Rhone glacier, which fans out at its foot in a somewhat analogous, but far less beautiful fashion.

Though not the most obtrusive, perhaps the most important feature displayed by the glacier was its stratification. Standing before its face at any point, it might be seen to be formed of definite layers and even of laminations. The photographic illustrations exhibit this in some measure, but the variation in light between the alternations of the more solid and the more porous ice was too delicate to be fully caught by the camera. The simplest form of the stratification consisted of alternations of porous, opaque white layers with solid translucent blue ones. The blue sheets were thin, while the white ones were relatively thick. The more conspicuous variety of stratification was formed by the introduction of rock rubbish between layers of relatively pure ice (Fig. 25). In the Fan glacier, this reached a far less notable development than in the glaciers which will hereafter claim our attention. But even there it was sufficiently pronounced to be a very notable feature. It is important to observe that the rocky material was distributed in definite horizons between the ice layers. It was not promiscuously scattered through the ice. The débris varied in coarseness from bowlders of large

dimensions downward to fine silt. The coarse and fine material were not separated. It was not a phenomenon of assortment Coarse and fine were arranged along the same horizons. The layers or laminæ of ice which were close together where only silt and sand were present separated so far as needful to admit bowlders. It was interesting to observe that the laminæ as they approached a bowlder parted, a portion curving over the bowlder and a portion curving under it. No good photographic illustrations of this were secured from this glacier, but fair ones from other glaciers will be given later. Many of these other glaciers show the phenomena of stratification and the inclusion of débris so much more clearly and pronouncedly that we may leave further details to be subsequently described.

The débris was enclosed almost exclusively in the basal beds, the upper portion of the glacier being almost entirely free from rocky material. The distribution throughout the lower layers was not strictly progressive from the base upwards. Higher layers sometimes contained more than lower ones, but the general fact of basal distribution was very pronounced. It was furthei observed that there was more débris in the layers near the sides of the glaciers than in the central portion. This is expressive of a law which somewhat widely obtains.

The top of the glacier was not reached by us, but from what could be seen it appeared to be essentially free from bowldery erratics, though somewhat discolored by atmospheric dust.

The débris which was embedded in the Fan glacier was largely composed of a hard pinkish sandstone derived from the middle member of the clastic series previously described. There was present, however, a considerable sprinkling of crystalline bowlders of the granitic type and occasionally bowlders of the greenstone type. If it is recalled that the source of this ice-flow was probably not more distant than the middle of the peninsula, the stratigraphy beneath the glacier is readily inferred. The uppermost member of the clastic series which occurs in the sides of the valley adjacent to the lower part of the glacier must soon be replaced at the surface by the rising of the pink sandstone

from beneath it. This in turn must soon be replaced by the crystalline terrane, which apparently constitutes the nucleus of the peninsula; indeed the crystalline terrane was afterwards observed to come out to the edge of the peninsula on its east side facing Bowdoin Bay. The material in the base of the glacier must apparently have been picked up from the rocky surface beneath the ice-cap. The derivation was apparently basal. Some part of it, however, may have been introduced laterally as it descended from the plateau into the valley. This seems to be indicated by the fact that the sides of the glacier contained somewhat more débris then the central portion.

The material in the ice was somewhat rubbed and scratched but not markedly so. Indeed the first impression was that of unsubdued angularity, but observation showed that some abrasion had been suffered by a considerable percentage of the blocks included. Well rounded and thoroughly striated bowlders were rare, though present. This, however, was scarcely typical. Similar material in other glaciers observed was notably bruised and scratched. Very likely the angularity in this instance is an effect of the open, free course which this glacier enjoyed in its relatively broad, straight valley.

At the edge of the ice, the embedded débris was being freed by melting and was dropping in front. The amount of débris in the ice being scant, the accumulation was small. There was an almost complete absence of any terminal moraine in front of the glacier. This will be seen by consulting the photographic illustrations. If any terminal ridge had been formed, it was either concealed beneath the margin of the glacier or by the frontal embankment above described. The latter could not have afforded a general concealment because its continuity was not complete. At some points the smooth gravel plain of the valley below could be traced up to the actual front of the ice. Nor was there any notable moraine along the sides of the glacier. As in the case of the Igloodahomyne glacier the drainage was chiefly accomplished by a stream on each side occupying a trench between it and the valley sides. Sometimes the lateral

stream tunneled under a portion of the ice, leaving a bridge arching over it from the body of the glacier to the side of the valley. In other cases the stream cut across the edge of the glacier dissevering a portion of it. These were cases in which the wash from the slope of the adjacent highlands was very considerable and encroached upon the glacier, burying the part that became dissevered. It was interesting to observe that much of this buried ice was exceptionally pure and solid. In other portions, however, it contained interstratified débris, and at some points there were irregular impregnations of rocky material.

On the east side there was a very significant phenomenon displayed in connection with an embossment or buried spur of rock (Fig. 28). The lateral stream of the glacier crossed the neck of rock connecting this with the valley side, cascading over it and cutting a channel in it. Next to the glacier the rock rose somewhat and was covered at the foot of the ice-wall which formed the side of the glacier by a talus derived from the lower layers of the ice. If reference is made to Figs. 28, 29, and 30 much unsatisfactory description may be avoided. It will be observed that near the base of the glacier there is a dark belt which consists largely of stony débris held in the matrix of ice. Below this, not well shown in the figure, there is ice less freely charged with rocky matter. Above this it will be seen that there are at intervals several dark lines, which are simply rock rubbish sandwiched between layers of ice. The notable feature is the curve which these assume. At the right, or up-stream end, the layers rise by beautiful curves which gradually flatten as they pass over the embossment. Beyond the summit they descend, gently at first, but more rapidly later. When they have reached a point some distance below the embossment, they bend backwards to varying extents and with various degrees of abruptness. The curvature is least abrupt near the embossment and increases generally with distance. The recurved portion nearest the embossment is short and its lower end soon becomes obscured by the fallen débris. The higher layers return farther

FIG. 29. Curving of laminæ, east side of Fan glacier. Photograph by Prof. Libbey.

FIG. 28. General view of laminæ curving over embossment of rock and drift. Photograph by Prof. Libbey.

FIG. 30. Recurving laminæ below embossment, east side Fan glacier.

and the one several feet above the broad dark band after curving sharply about runs several rods backwards before it is lost from sight under the sloping débris. (See Figs. 29 and 30.)

The drumloidal[1] nature of the curve described by these layers is very suggestive, and it is perhaps not too much to believe that the essential principles of drumlin formation are here expressed. It will be wise, perhaps, to defer inferences and special discussions until other phenomena of like nature are described and a broader basis for induction is laid.

T. C. CHAMBERLIN.

[1] I suppose that drumlinoidal is the rigidly correct adjective to use here, but as drumloidal is briefer and better in itself, it seems preferable to be governed by the euphonies and utilities of language than by the stiff formulas of a conventional grammar.

Studies for Students.

GEOLOGIC STUDY OF MIGRATION OF MARINE INVERTEBRATES.

CONTENTS.

INTRODUCTION.

THE migration of invertebrates is necessarily too slow to be observed in a few years, and only many successive generations of observers could throw light on it. While the present habits of these animals may be studied and inferences drawn as to their history, these inferences are probably often incorrect. The common inference that fossil corals indicate a warm sea is an example; by this method the existence of a tropical sea in the Arctic regions during Palæozoic time has been inferred, and therefore great changes in physical geography. But it is well known that the elephant and the rhinoceros, which we regard as typical tropical animals, lived in the Arctic regions of the northern

hemisphere during the Glacial period. Also the Bryozoan group Cyclostomata are, as fossils, widely distributed in temperate regions, but the living forms of these are decidedly Arctic.

The present distribution of animals shows many anomalies, many groups being present where naturally, according to their habits elsewhere, they ought to be lacking, and being absent where, according to analogy, they ought to be present.

It is clear then that a study of the present distribution and habits of marine animals can throw little light on their history. But the geologist does not confine his observations to the present; geologic history is a book whose leaves are scattered in many parts of the earth, and each observer gathers some of these leaves.

A study of the distribution of animals in past time ought to explain their present occurrence, and the laws governing their distribution; and incidentally light should be thrown on the extinction of faunas, and upon changes in physical geography that accompanied and caused the migrations and extinctions.

ZOÖLOGICAL PROVINCES.

Modern Provinces.—One of the first facts in the study of geographic zoölogy that attracted the attention of naturalists was that animals are not distributed strictly according to climate, or other physical conditions. This was inexplicable, according to the views then held. The work of Edward Forbes upon the *Natural History of the European Seas* began the scientific study of the distribution of marine animals. Forbes formulated the theory of generic and specific centers. Each genus and each species was to him a reality, and by distribution of these from the centers he satisfactorily accounted for their occurrence in other places. Although reasoning upon the theory of special creation for each species, Forbes recognized the fact that species and genera are never intermittent except locally. His results therefore do not differ in any respect from those obtained on the basis of development of one species out of another. He showed too that while separated regions under the same conditions show great similarity of faunas, this similarity is due rather to representative than to

identical species or genera. What better argument could be adduced for the influence of surroundings on development?

S. P. Woodward[1] while working upon the same theory as Forbes reaches the following conclusion: "Meanwhile it may be stated that according to this evidence [that derived by Forbes from Palæontology] the faunas of the provinces are of various ages, and that their origin is connected with former (often very remote) geological changes, and a different distribution of land and water over the surface of the globe." It must be remembered that this was written several years before the publication of Darwin's *Origin of Species*, at a time when the teachings of Lamarck had been practically forgotten, and by an author that believed in the reality of species.

The marine provinces that were proposed by Woodward[2] for the invertebrates hold good even now. They are as follows: (1) Arctic, (2) Boreal, (3) Celtic, (4) Lusitanian, (5) Aralo-Caspian, (6) W. African, (7) S. African, (8) Indo-Pacific, (9) Australo-Zealandic, (10) Japonic, (11) Aleutian, (12) Californian, (13) Panamic, (14) Peruvian, (15) Magellanic, (16) Patagonian, (17) Caribbean.

And these provinces[3] are grouped naturally into great regions:

"The tropical and sub-tropical provinces might naturally be grouped in three principal vivisions, viz., the Atlantic, the Indo-Pacific, and the West-American,—divisions which are bounded by meridians of longitude, not by parallels of latitude. The Arctic province is comparatively small and exceptional; and the three most southern faunas of America, Africa, and Australia differ extremely, but not on account of climate." An application of this same method enabled Wallace to write his *Geographical Distribution of Animals* and to place the study of the geographic distribution of all animals on a scientific basis.

[1] Manual of the Mollusca, 1856, p. 352.

[2] Manual of the Mollusca, 1856.

[3] Loc. cit., p. 353.

ANCIENT PROVINCES.

There were no such things as universal faunas, even in remote geologic time; there have always been barriers of continent and ocean, and probably too of climate, ever since life existed on the earth. Only the deep sea faunas could be universal, if oceanic bottoms had been stable, but even they are not universal now, nor have they remained unchanged in time.

Barrande showed that the known Cambrian and Silurian faunas could be divided into well-defined provinces, and the recent work of Professor Walcott has extended greatly our knowledge of the distribution of Cambrian animals.

For the geographic study of Devonian faunas we are especially indebted to Barrende,[1] and H. S. Williams.[2]

It has been shown conclusively by the latter author that in Lower and Middle Devonian there was a North-South American region, and a Eurasian region; and that during Upper Devonian times the regions had changed so that the grouping was into the Eurasian-North American, and the South American-South African.

We owe most of our knowledge of the faunal geography of the Carboniferous to Professor Waagen.[3] He has shown that during the Carboniferous there were two great regions corresponding to the northern and the southern hemispheres, and that within these were provinces more or less sharply defined. But these regions and provinces by no means agreed with those of the older Palæozoic.

Mojsisovics[4] has divided the known Triassic faunas into two great regions, the European and the Pacific, and these in turn into provinces; the European Mediterranean province, the Arctic; the Himalayan, which is intermediate between Arctic and Mediterranean; and the American.

[1] Système Silur. Bohème.

[2] Cuboides Zone and its Fauna, Bull. Geol. Soc. Amer., Vol. I.

[3] Pal. Indica. Salt Range Fossils. Geological Results.

[4] Arktische Triasfaunen, Mém. Acad. Sci. St. Petersbourg, VII. Series, Vol. XXXIII., No. 6.

But during the Lower Trias the Arctic, the Himalayan, and the American provinces had closely allied faunas, and might be grouped together in contrast to the Mediterranean. In the Middle Trias, however, the American Triassic province was being gradually cut off from the Arctic, and communication established with the Mediterranean. This connection through the Himalayan province was very complete in the Upper Trias, and all three might be grouped under one region, the Mediterranean-Indian-American.

Neumayr[1] has worked out the provinces of Jurassic time, and grouped them in two regions, the Boreal, and the Central-Mediterranean. He has also traced out for that time the distribution of climatic zones by means of the Boreal type, the North Temperate type, the Alpine or Equatorial, and the South Temperate.

To the Boreal region belong the Russian, the Siberian, the Himalayan, and the Alaskan provinces. To the Central Mediterranean region belong the Northern European, the Alpine, the Salt Range, the Southern Indian, the Australasian, South American, and the Western American. But during Upper Jura the Western American province took on an Arctic character, and certainly became part of the Boreal region. Thus these regions and provinces will not hold good for any long-time division, but were always, though slowly, changing.

The study of the distribution of fossil faunas as influenced by climate was begun by Ferdinand Roemer,[2] who recognized that the Cretaceous of England, northern France and Germany has a fauna similar to that of New Jersey, and that the faunas of southern Europe, north Africa, and Texas are similar. These differences Roemer ascribed to climate, noting that at that time, as today, in America the isothermal lines came much further south than in Europe. Neumayr[3] has carried these studies forward, correlating the various observations made since Roemer's time.

[1] "Geogr. Verbreitung der Juraformation," and "Klimatische Zonen wärend Jura und Kreidezeit."

[2] Kreidebildungen von Texas, Bonn, 1852.

[3] Klimatische Zonen wärend Jura und Kreidezeit.

It is now known that the Cretaceous of South America belongs to the tropical type, as does also that of Mexico.

Still more recent observations have shown that the Cretaceous of western North America belonged during the Neocomian or Knoxville to the Boreal or Russian type, but this resemblance soon died out, and that the Horsetown or Gault fauna was of central European type, like that of India. This kinship to the Indian faunas persisted until the end of the Cretaceous. Since Cretaceous time the marine provinces seem to coincide closely with the existing boundaries of the temperature and shore lines.

MIGRATION.

Causes of migration.—The lower forms of life produce many more young than can possibly come to maturity; hence a lively competition ensues between those of like character as well as between those that are different. Under these conditions an equilibrium is attained, the field supports the maximum population, and all others migrate or perish.

Thus migration would be a necessity even if the conditions remained always the same and the competition were always between members of the same fauna. But conditions never remain the same. The same causes drive individuals from one habitat and to another, and disturb the equilibrium there established. A disturbance taking place in an unimportant part of a province must therefore disturb the whole zoölogical region. And if we add to this changes in physical geography, we see that constant migration and intermigration must be a necessity. Any rising or sinking of shore lines would drive the inhabitants from their dwelling places; each change in the outline of continents changes the direction of currents, and thus has a marked influence on migration.

Extinction of faunas.—Today it is noticed that when the struggle for existence becomes too severe for a species it disappears. But the reason for this disappearance has always been uncertain. In geologic history a species has a certain length of life and dies out, never to reappear. The supposed contemporaneous extinc-

tion of a species all over the earth has led to the theory that species, like individuals, have a limited life, and that in time they reach a stage of development where they can go no further, and then of necessity die out.

This idea would be all very well if species dropped out one at a time, but in reality they usually go and come by faunas. It would seem, then, that changes in physical geography have had more to do with the extinction of faunas then anything else. This becomes the more probable when we reflect that species are not extinguished contemporaneously over the earth, but rather that their appearance and extinction have been used by geologists in a misleading way to prove synchronism of strata.

Remarkable cases of survival of types have long been known, as of *Trigonia* in the Australian waters, and of *Pholadomya* in the Antilles. Survivals of faunas are constantly coming to light. Dr. W. H. Dall[1] has shown that a large proportion of the Pliocene and even Miocene invertebrates of the Southern Atlantic Gulf states are still found living in the archibenthal region off the present coast. The same thing is true of the California coast, but here we have an even more remarkable example. Dr. A. C. Lawson,[2] from purely geologic evidence, has reached the conclusion that Santa Catalina Island has remained above water during Quaternary time, while most of the neighboring country was submerged. This stability of conditions has shown itself in a unique survival of the marine fauna, for Dr. Cooper's[3] list of the fossil mollusca of the California coast shows five species still living on Catalina that are known elsewhere only as fossils, and many species that are now known living in other remote zoölogical provinces. Similar cases of survival occur in ancient geologic formations.

Dr. C. R. Keys[4] called attention to a reappearance of a Waverly fauna in the Burlington of Missouri. A similar occur-

[1] Bull. Mus. Comp. Zoöl., Vol. XII., No. 6, p. 186.

[2] Univ. Calif. Bull. Dept. Geol., Vol. I., No. 4, p. 135.

[3] Calif. State Mining Bureau, Seventh An. Rep. 1887.

[4] Am. Jour. Sci., Dec. 1892, p. 447.

rence was described by the writer[1] and by Professor H. S. Williams[2] in the Fayetteville Shale, Lower Carboniferous, of Arkansas. A survival of a Devonian fauna in rocks of Lower Carboniferous age has been described from Nevada by Professor C. D. Walcott,[3] and from California by the writer.[4]

It is becoming more evident all the time that the range of faunas, instead of being usually the same in widely separated regions, is usually different, and that strata can no longer be called synchronous from the occurrence in them of similar faunas.

In reality they can no longer be called homotaxial with any degree of certainty, unless we know in what direction the faunas migrated, since homotaxis in the palæontologic sense does not agree with homotaxis in the stratigraphic sense.

The extensive extinction of life at one place earlier than in another has also been noted. Professor W. Waagen[5] has suggested that the glaciation in the southern hemisphere toward the end of the Carboniferous killed off the Palæozoic flora earlier than was the case in regions where there was no glaciation. Such phenomena approach the nature of "catastrophes," and show that Cuvier's doctrine was not so far wrong after all.

The study of the distribution of faunas in the past seems to show that their extinction has been chiefly due to changes in physical geography; and that where conditions remained constant the faunas remained unchanged. This study too suggests that no part of the earth has remained unchanged, for while some of the abysmal regions may be very old, even their faunas are of comparatively modern aspect.

MEANS OF MIGRATION.[6]

Few invertebrates are rapid swimmers. Many are attached forms and the majority are only crawlers. But all are free at

[1] Jour. Geol., Vol. II., p. 198.

[2] Am. Jour. Sci., III. Ser. Vol. 49, pp. 94–101.

[3] Monograph VIII. U. S. Geol. Survey.

[4] Jour. Geol., Vol. II., p. 595.

[5] Pal. Indica. Salt Range Fossils. Geol. Results, p. 240.

[6] Accidental distribution need not be considered here; it may have occurred, but must have been very rare.

some time in the life of the individual or cycle. This is often in the larval state, but it is known that certain species of brachiopods, which are swimmers only in the *cephalula* stage, are distributed over thousands of miles. It is an important fact that ammonites, which were free in the adult stage, and may have been swimmers, though most probably chiefly crawlers, are not distributed much more widely than lamellibranchs or others of the lower invertebrates. Thus the Upper Triassic fauna of California contains many species that are found in the Alps and the Himalayas, and among these there are several species of the *Aviculidæ*, which in the adult stage were attached by a byssus. The Lower Cretaceous Knoxville fauna of California contains along with ammonites a good representation of European lamellibranchs; and the Horsetown and Chico faunas of California contain fully as many species of lower invertebrates as of ammonites that may with probability be referred to foreign species. It is clear, then, that their distribution has been due to faunal, rather than to individual migration. Faunal migration can only be possible under physical agencies acting slowly, and on a large scale. Marine currents along shore lines have been efficient aids to migration, not so much by transporting the young, as by transporting conditions suitable for life.

Even with our currents continental margins offer ample opportunities for faunal migration, for the crawling adults or the swimming young can find the constant conditions of depth, temperature and food supply suitable for their life.

Dr. W. H. Dall[1] has recently shown that tides on the archibenthal continental margins have been influential in distributing faunas. But probably the great agent of distribution has been the slow shifting of shore lines, which not only aids but also compels migration.

BARRIERS TO MIGRATION.

Land barriers.—Land masses present an insuperable barrier to all marine invertebrates; but if the bodies of land are short, and

[1] Bull. Mus. Comp. Zoöl., Vol. XII., No. 6, p. 179.

do not reach into polar waters, animals can easily pass around the ends. Thus the molluscan fauna of the Mediterranean does not differ appreciably from that of the English waters, because in the passage around the peninsula of Spain animals remain in temperate waters, and under nearly the same conditions.

On the other hand, the Isthmus of Panama separates two faunas absolutely distinct from each other; the same thing is true of the Isthmus of Suez.

East and west land masses would therefore not be very effectual barriers since they would not be so likely to extend into polar waters or into great differences of temperature.

Climatic zones.—That climatic zones are today partial barriers to migrants along the coast is shown by the difference in faunas living in northern and in southern latitudes under the same conditions. From the very nature of the case we should expect that cold water species would be able to cross climatic zones more easily than those adapted to warm water, since, as Dr. W. H. Dall[1] has shown, a fall of a very few degrees below the temperature favorable to life is more destructive than a rise of many degrees.

In the present we have no means of testing this, but facts brought to light by geology confirm it. The Jura of Central Europe and of the Argentine Republic in South America have the same fauna, which, in reaching one of these regions from the other, must have passed from temperate waters through tropical, and into temperate seas again. Also the faunas of the uppermost Jura and the lowest Cretaceous of Russia, which must have been Arctic in character, have migrated southward along the West Coast, almost into tropical waters. On the other hand we know of no case where equatorial faunas have passed through Arctic regions and even passages from tropical into temperate regions must be exceedingly difficult.

The genera *Lytoceras* and *Phylloceras* are common in the Neocomian, Lower Cretaceous beds of southern Europe; but although these waters were undoubtedly in direct connection

[1] Bull. Mus. Comp. Zoöl., Vol. XII., No. 6, p. 180.

with those of northern Europe, *Lytoceras* and *Phylloceras* are lacking in the latter region. Also in the lower part of the California Knoxville beds the above mentioned genera are unknown, and come in only higher up where the first members of the tropical Indian fauna began to come in.

Water barriers.—By far the greater part of marine animals live near the shore, and are unable to exist under other conditions. To these an abysmal sea is as impassible a barrier as a continent. But an east-west sea affords good opportunity for passage from one side to the other simply by slow progress along the margin. The fauna of the Mediterranean is a good evidence of this, the animals on the European shores not differing appreciably from those on the African.

And even on the opposite sides of great north and south oceans there are usually many species in common ; the Atlantic shore American fauna has many European species, and the Pacific shore harbors many from Asiatic waters. Their passage was effected in most cases along continental borders that have since been obliterated by subsidence and erosion. We have an abundance of independent geologic evidence that such recent changes have taken place, for example the destruction of the Antillean continent since Tertiary time, as worked out by Dr. J. W. Spencer.[1]

No doubt just such great recent changes in the distribution of land and water could be worked out in the Indian ocean, by application of the same method of study. The studies of Neumayr,[2] Waagen[3] and Suess[4] have demonstrated the existence of a continent in that region during late Palæozoic and early Mesozoic times, connecting Australia with Asia.

By a study of the geographic distribution of animals Wallace[5] has shown that in comparatively recent times Australia was

[1] Bull. Geol. Soc. Am., Vol. VI., 103–140.

[2] Geographische Verbreitung der Jura formation.

[3] Palæontologia Indica.

[4] Antlitz der Erde.

[5] Geograph. Distrib. Animals, Vol. II., The Australian region, pp. 387–485.

connected with many of the now scattered islands of the Indian Archipelago, but was separated from Asia.

Deep seas afford no barriers to rapid swimmers or to any pelagic forms, or to dwellers in the deeps. These approach much more nearly universal distribution, the first two being checked only by continental barriers, and the latter only by shallow waters.

CRITERIA OF MIGRATIONS.

Occurrence of identical or very closely related species and faunas in widely separated localities is good evidence of migration from one of these localities to the other, or from another region to both of them. In most cases, however, what are called identical species are in reality only representative forms.

As long as ideas about stratigraphic units were loose, and species had too broad a significance, it was impossible to recognize slight changes in faunas and age. Oppel[1] from his study of the Jura gave to geology the idea of stratigraphic zones, each with its characteristic animals. He recognized the importance of selecting types of great horizontal and narrow vertical distribution, and for this reason, where it was possible, chose ammonites as zone fossils.

This work would never have been possible had not Barrande[2] introduced an extremely narrow idea of species. Neumayr carried this study further by introducing the idea of "mutations" for genetic series of forms occurring in succeeding zones.

The use of these principles enables the naturalist to draw sharp lines between successive faunas.

Sporadic occurrence.—It is often noticed that species or faunas are intermittent in their occurrence, and this too when it is not due to difference of facies. Just such a case is the reappearance of the Waverly fauna in higher beds of the Lower Carboniferous of Missouri and Arkansas, already alluded to in this paper. The intercalations of marine beds in the fresh-water deposits of the Coal Measures is another good example.

[1] Juraformation.

[2] Système Silur. Centre Bohème.

In the Jura of northern Europe, according to Neumayr,[1] the genera *Lytoceras* and *Phylloceras* appear only sporadically, being lacking entirely in sixteen zones; and the known species in that region do not belong to a genetic series. But in southern Europe these genera appear plentifully in all the zones, and do represent genetic series.

The migration northward at several successive periods is thus clearly established. In these same beds the genus *Amaltheus* also appears intermittently; but no region is yet known where *Amaltheus* developed continuously. Among the Jurassic ammonites of northern Europe there are a number of cryptogenic types, most of which coincide with the *Amaltheidæ* in their appearance and therefore came from the same region.

These facts go to show that the principles on which Barrande's[2] doctrine of colonies was founded were not far wrong, although it has since been found that his colonies were only younger rocks carried into the midst of older beds by dislocations.[3] Barrande's idea was that younger faunas are sometimes intercalated with older ones by changes in physical geography. The modern doctrine of colonies on the other hand is that older faunas have often been preserved by survival in places where no great changes have taken place, and that these older faunas have been intercalated with the younger by changes in physical geography.

Heterochronous appearance.—By heterochronous appearance of forms is meant their occurrence at different horizons in separated regions. Now it is well known that a species seldom occurs at exactly the same time in two widely separated places; it must originate at the one and migrate towards the other. This migration takes time, and the species may be entirely extinct at the point of origin before it reaches the second place. But geologists have commonly used species as criteria of horizons, when in

[1] Jahrb. K. K. Geol. Reichsanstalt Wien. Bd. 28, 1878. Ueber unvermittelt auftretende Cephalopodentypen im Jura Mittel-Europas.

[2] Système Silur. Centre Bohème, Vol. I., p. 73, etc.

[3] J. E. Marr, Quart. Jour. Geol. Soc., 1880, p. 605, 1882, p. 313.

reality this should be subject to much greater limitations than even the ideas of homotaxis, as formulated by Huxley,[1] would demand.

Faunas need not and do not appear at the same horizon, nor even in the same order of succession, all over the world, for an intermigration between two distant localities would produce an apparent inversion of the two faunas at either place.

The genus *Clymenia*, according to Professor J. M. Clarke,[2] appears in the *Goniatites intumescens* beds of New York ; in Europe *Clymenia* is wholly unknown in the *Intumescens* fauna, but is the characteristic form of the next higher division of the Devonian, where the *Intumescens* fauna is already extinct.

In the Upper Trias, Karnic stage, of California, *Rhabdoceras* and *Halorites* occur, although *Rhabdoceras* is known in the Alps only from the higher Jura stage, and *Halorites* in both Alps and Himalayas is characteristic of the latter horizon. Also in the Hosselkus limestone, Upper Trias, of Shasta county, California, *Trachyceras* and *Protrachyceras* occur, in the zone of *Tropites subbullatus*, and associated in the same rocks with a characteristic *Subbullatus* fauna ; but in the Alps and in the Himalayas *Trachyceras* and *Protrachyceras* are older than the *Subbullatus* fauna, and never occur in the same beds with it. The question then remains, Did *Trachyceras* and *Protrachyceras* survive longer in America than in Asia and Europe, or did the *Subbullatus* fauna reach here earlier? The researches of Mojsisovics[3] show that *Tropites* is probably indigenous to the Arctic-Pacific Triassic province, and that *Trachyceras* is endemic in the Mediterranean region.

Heterochthonous[4] *faunas.*—In many cases faunas appear unheralded by local ancestors, having been brought in by migration from other regions.

Thus in America, according to Professor H. S. Williams,[5] the

[1] Quart. Jour. Geol. Soc. XVIII., 1862, 46.

[2] Am. Jour. Sci., III. Ser., Vol. XLIII., p. 57.

[3] Arktische Triasfaunen, p. 148 and Abhandl. K. K. Geol. Reichsanstalt Wien., Vol. VI., Part II., Second half, p. 7.

[4] From ἕτερος, *other*, and χθών, *land*.

[5] Cuboides Zone and its Fauna. Bull. Geol. Soc. Am., Vol. I.

Cuboides fauna is exotic, appearing suddenly in the Tully limestone at the base of the Upper Devonian; but in Europe the *Cuboides* fauna belongs to a genetic series, and is autochthonous.

The *Tropites* fauna of the Karnic stage, Upper Trias, is heterochthonous both in Europe, Asia and America, but the place where this fauna belongs to a genetic series is still unknown.

In the same way several of the faunas of the Jura and Cretaceous in California appear to be heterochthonous; some of these are known to be endemic in certain regions, others, on the contrary, are not.

CONCLUSION.

From the foregoing facts it will be seen that migration increases the struggle for existence by introducing forms into new conditions, to which they must adapt themselves, and that it also breaks up the established equilibrium and introduces new rivals, thus affecting autochthonous forms. Migration therefore works hand in hand with natural selection in killing off weaker forms, and changing the plastic ones by adaptation.

It is also clear that migration strengthens the geologic evidence of great changes in physical geography in past time. Regions that now are continents have certainly been seas, and seas have probably been continents.

Even the ocean abysses need not have been permanent, for their faunas have a modern aspect, and therefore must have changed from the old types. But from what we have seen of survivals of faunas under favorable conditions, we infer that without changes in conditions there is no reason why they should have changed. The natural inference then is that neither continental plateaux nor oceanic abysses have been permanent.

JAMES PERRIN SMITH.

STANFORD UNIVERSITY,
California, May, 1895.

EDITORIAL.

THERE is nothing more remarkable in the whole range of geological history than the peculiar associations and successions of contrasted faunas and floras and of glacial beds and coal deposits in the southern portion of the eastern continent during the closing Palæozoic and opening Mesozoic eras. Scarcely less interesting are the shifting relations of faunas and floras and the implied geographic connections and disseverances of the ages which follow these and find expression in the eastern part of the same continent and the western portion of our own. The contributions of the last two or three decades from the circum-Pacific provinces have done much to break down current interpretations of geological history and to build up new ones. And there is doubtless more to come. In this field, with little question, lies the solution of many radical problems. It is therefore a matter of congratulation that, beside the work of the national and state surveys, two rapidly rising universities on our Pacific border are vigorously pushing geological inquiry and rapidly giving the public the benefit of their results. The nearly simultaneous offering of three papers relating to California geology, and the knowledge that others were in preparation, suggested the gathering of these into a California number of the JOURNAL, both as a means of concentrating interest and as a recognition of the richness of the field and the industry and ability of its workers. T. C. C.

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In the editorial of the last number the words "and ten" on page 341 at the end of the fifth line from the bottom should be omitted.

PUBLICATIONS.

Note on Mr. Kümmel's Review of the "Reconstruction of the Antillean Continent."

Mr. Kümmel's review of the paper under the above title is of particular interest in calling attention to impressions which topics not considered by the author produce upon a conservative reviewer, somewhat hesitating in accepting the recently set-forth theory of great continental elevations, although willing to admit an equal amount of terrestrial movement, providing much of it be confined to the sinking of the floor of the sea. The startling character of the changes of level in late times has impressed itself upon none more than the author, for it took several years to overcome the prejudice against an apparent hypothesis which had not commonly entered into our literature. The papers so far published are only part of those ready, or in preparation, on account of extended researches in the West Indies and Mexico since the appearance of the paper reviewed by Mr. Kümmel. Concerning these investigations, it may be said that they not only confirm in a most satisfactory manner the conclusions reached at an earlier date, but they supply many deficiencies which were found in the preparation of the earlier work, and also carry the researches much farther than had been anticipated. These results will be offered in course of time to the public; but even with these published, the work must not be considered as scarcely more than commenced, for it is impossible to predict to what limits it will reach.

Mr. Kümmel says that the author makes no reference to sunken delta deposits, and therefore infers that they do not exist. Not at all. It is one of the several topics which along with the more important questions of the slopes of the drowned valleys, has not been discussed, and which the reviewer deprecates as not having been considered,—a point well taken. The slope of the sunken valleys ought not to be compared with those of the eastern part of the continent, but with those on the margins of the Mexican table lands and other regions within the tropics, while the declivities of the continental valleys of the

east are comparable with those occupying the interior of the plateaus. The descent of the canyon of the Colorado alone cannot be taken, but that of the reaches of the canyon and of the valley to where it emerges on the highlands of the Great Basin at an elevation of 7000 or 8000 feet. The descents of these valleys are not appreciated by their mean slopes, which in part are insignificant but in other places they are precipitous. It is necessary to analyze the details. Thus the writer has observed the descents of the existing land valleys through thousands of feet with characters and slopes comparable with those sunken across the sunken coast plains. This study will be brought out in detail.

Mr. Kümmel gives prominence to the hypothesis of the extraordinary sinking of the floor of the Mexican Gulf, etc., thereby accounting for the greater portion of the subsidence of the valleys. It is gratifying that the reviewer accepts the evidence of the changes of level to the same proportion as the author, although suggesting a somewhat different character. The question of determining the amount of local deformation of the continent as different from the general movement is doubtless one of the difficult points; but the author allowed any amount up to 4000 feet for covering the abyssmal subsidence in excess of the general movement south of the Mississippi. Whether too much or too little cannot yet be said. But amongst the Bahamas there is a better yard-stick. The drowned valleys reach to a depth of 12,000 or 14,000 feet, amongst islands, banks, and in the edges of the continental plateau, which last is submerged to no more than 4000 feet. Thus we cannot deduct for exaggerated marginal depression more than this amount in some places, and in others not even so much. However, the writer hopes to remove a few of the obscurities in the continental history, and thanks the reviewer for pointing out some of the greatest needs in elucidating the investigations of the great changes of level of land and sea, much new data being already at hand.

J. W. Spencer.

Ueber Archaeische Ergussgesteine aus Småland. Von Otto Nordenskjöld. (Bull. of the Geol. Instit. of Upsala, Vol. I., No. 2, 1893, pp. 125.)

Of all rock names probably the most indefinite, and at times the most convenient, are the names: *greenstone* in America, *petrosilex* in France, *felsite* in England, and *hälleflinta* in Sweden. Many, and

often diverse types, have been grouped together by this means, and confusion has often resulted.

This paper of Dr. Nordenskjöld's forms a very important contribution to our knowledge of the Archæan rocks, and it adds new meaning to these abused terms. The Scandinavian peninsula has long been classic ground for Archæan studies, and nowhere is that formation better represented, or its problems more varied. Småland is a Baltic province comprising three districts of southern Sweden, and it is about twenty-five miles distant from Christiania. The surface occupied by the rocks described is over 10,000 square kilometers. In this paper the hälleflinta and porphyries are particularly described, and references are made to the preceding work of Eichstadt and Holst on the basalts, gabbros and other basic rocks. The term *hälleflinta* is a very old one, and designated a gneissoid, opaque rock which accompanied the ores. It was afterward applied to all rocks with a compact structure. A complete summary of the literature on this subject is given, and the progress in the knowledge of the true nature of such rocks is also pointed out. They were long regarded as of sedimentary origin. In 1877, Allport, in England, proved the Shropshire greenstones to be acid eruptives, and he was soon supported by the other English petrographers. Rocks similar to the Småland types were described by Irving in the copper-bearing series, by Williams in the South Mountain district, and by Sederholm in Finland.

The study of the Småland rocks was commenced by Nordenskjöld in 1889, and their eruptive origin first shown in 1892. In this area occur four belts of the *hälleflinta*, each 60 to 100 kilometers long and 10 to 15 kilometers wide. They contain neither glass nor microfelsite, and so cannot be classed as felsophyres or vitrophyres; further, they are identical with the South Mountain rhyolites. The granites of the area are both coarse and fine grained; the latter, or aplitic variety, grades into the *hälleflinta*, and it often contains dark basic patches. The porphyries occupy a position between the granites and the eovolcanics, but they are allied to both. The granophyres are closely connected with the Lönneberg eodacite, especially near Näshult, where the rock is rich in augite. Porphyritic dyke rocks occur in many places, but always in or near the hälleflint areas. They are identical with the massive porphyries, and they represent the last stage of the eruption. They occur by the hundred close together and parallel, but always separate.

The rocks so far described show but little variation, and they are mainly important in their transition to the next series of eovolcanics which cover nearly one-half of the area. The acid eruptives include the eorhyolites and eodacites which chemically are almost identicaf with the younger rhyolites and dacites. They possess a porphyritic structure and a black felsitic groundmass. All the rocks described in the paper show strong mechanical deformations, but chemical alteration of the minerals in this series is so rare that it is probable they were broken during their eruption. The structure is almost crypto-crystalline, and it varies even in the same thin section. A considerable number of accessory minerals occur and pseudomorphs are quite common. Epidote is present, as in the South Mountain rocks. In the eorhyolites eutaxitic structure is less common than in the other types. The groundmass is weakly doubly refracting and red in color due to hematite flakes. Among the pyroclastic rocks occur the volcanic equivalents of the porphyries. Quartz is rarely present, yet the rocks are more acid than the eodacites. Under the primary breccias are included the eutaxites and the agglomerate lavas, the former showing flow structure, the latter being fragmental. The agglomerates possess the rhyolitic structure of Rutley or the aschen structure of Mügge, which argues for a tuff-like origin. The absence of foliation and transition into the eutaxites speaks against this view, thus leaving the question open. Near Kolsjön occur fine examples of perlitic partings, spherulites and lithophysæ. The chemical work of Santesson shows no essential difference from the younger eruptives. The presence of manganese allies these rocks to the South Mountain types, and the high alkali percentage joins them with the keratophyres and dacites.

In age the rocks are pre-Cambrian. Sederholm divides the Archæan into three divisions: Katarchæan, Bottnian, Karelian (Algonkian). The Småland granites and hälleflinta are katarchæan and belong to the group of oldest known volcanics. There are no safe mineralogical distinctions between the eovolcanic and the younger porphyries; but there is a difference of habit. In the older rocks there is a greater occurrence of crypto-crystalline structure and less of the granophyric or microfelsitic arrangement. The boundaries of the mineral constituents are indistinct, and there is a greater number of secondary constituents. Spherulites and other characters also enter. The eruptive character of the rocks is proved by:

1. Absence of true stratification.

2. Order of crystallization.
3. Flow structure.
4. Implication structures (micro, and crypto-pegmatite).
5. Spherulitic structure.
6. Spheroidal (kugel) structure.
7. Perlitic partings.

The original appearance of these rocks cannot be described, for they have been completely altered by dynamo metamorphism and its attendant changes, among which devitrification has been most active.

Throughout the paper the prefix *eo*, as in eorhyolite, is used to show the relation of the old volcanic to the newer type with which it is closely connected. This brings in the troublesome age question in classification. At present there is a reaction against the use of age terms in petrography, and it would be better to employ the prefix *apo*, as suggested at nearly the same time by Miss Bascom,[1] and thus avoid the old discussions and objections. Dr. Nordenskjöld refers to this prefix in a note at the end of his paper, and signifies his willingness to adopt the *apo* prefix if it is regarded by petrographers as a better one.

G. PERRY GRIMSLEY.

[Several reviews intended for this number are deferred to give place to standard articles.]

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